ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

MÁSTER EN INGENIERÍA INDUSTRIAL

A REAL TIME E-BIKE PARKING AND SHARING MANAGEMENT SYSTEM

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Supervisor: Dr. Haibo Chen

S3Innovation, Brussels

May 2018

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A REAL TIME E-BIKE PARKING AND SHARING MANAGEMENT SYSTEM

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A REAL TIME E-BIKE PARKING AND SHARING MANAGEMENT SYSTEM

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Acknowledgments

First of all, I would like to thank the S3 family for their collaboration and their support in the development of this product. Thank you for the chance of working with you and learning from your experience.

Thanks to my supervisor Mr. Haibo Chen for his time and effort in every step of the process.

Thanks to my friends from the IIT for their patience and for attending to my endless questions.

Thanks to my family for supporting me to be able to have this experience which has made me a better person and a better professional.

Finally, thanks to you Isabel, for being the cornerstone in my life and for being there whenever I need you.

SISEMA DE GESTIÓN EN TIEMPO REAL PARA PARKING Y SHARING PARA BICICLETAS ELÉCTRICAS

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Director: Chen, Haibo.
Entidad colaboradora: S3Innovation

RESUMEN DEL PROYECTO

La movilidad eléctrica será uno de los principales factores en la reducción del impacto ambiental de la sociedad. Esto es especialmente relevante en el tránsito urbano dónde es cada vez más importante la búsqueda de un modelo sostenible para los viajes de la última milla. En respuesta a esto se ha creado un producto para integrarse con bicicletas eléctricas y que permite responder a la demanda en tiempo real gracias a una extrema flexibilidad en el diseño y a unas capacidades de conectividad superiores mediante tecnología IoT.

Palabras clave: bicicletas eléctricas, parking, *sharing*, IoT, Smart City, transporte.

1. Introducción

La electrificación del transporte es un hecho actual, que cada vez cobra más inercia. Es una tendencia que afecta a todo tipo de vehículos y que abre nuevas puertas de modelos de transporte en entornos de alta densidad como son las ciudades. Por ello, las bicicletas eléctricas ofrecen una gran cantidad de ventajas para los viajes de la última milla y por ello se ve necesario la creación de una plataforma de aparcamiento que permita responder a la demanda en tiempo real, por lo que debe ser flexible, estar conectada y además tener un coste reducido y así ser fácilmente introducido al mercado.

2. Definición del proyecto

En este proyecto se ha desarrollado distintos aspectos de un sistema de parking y recarga para bicicletas eléctricas dentro de un servicio de *sharing* capaz de responder en tiempo real a la demanda gracias a un diseño modular y la tecnología de IoT. Se trata del MOD-Hub y del cual se ha desarrollado toda la arquitectura del sistema, se ha realizado el proceso de ingeniería general y la ingeniería de detalle de la parte de control y comunicaciones. Por último, además se ha realizado un estudio de la instalación para el autoconsumo con paneles solares.

3. Descripción del modelo/sistema/herramienta

El MOD-Hub, por lo tanto, se trata de una serie de módulos para guardar bicicletas con un diseño tal que se pueden disponer en círculo o linealmente para adaptarse al entorno. Cuenta con una forma poliédrica que minimiza el espacio ocupado a la vez que garantiza sus múltiples configuraciones. Estos módulos se conectan formando grupos, los cuales a través de conectividad inalámbrica son capaces de transmitir datos a un servicio cloud centralizado que permite tanto su control como monitorización continua. De esta manera se puede conocer el estado del sistema en cualquier momento para así adaptarse a la demanda de una forma óptima. Los módulos cuentan con acceso a través de identificación por radiofrecuencia (RFID) y mediante acceso por una app móvil.

Además, son capaces de proporcionar información sobre el estado de las bicicletas en su interior.

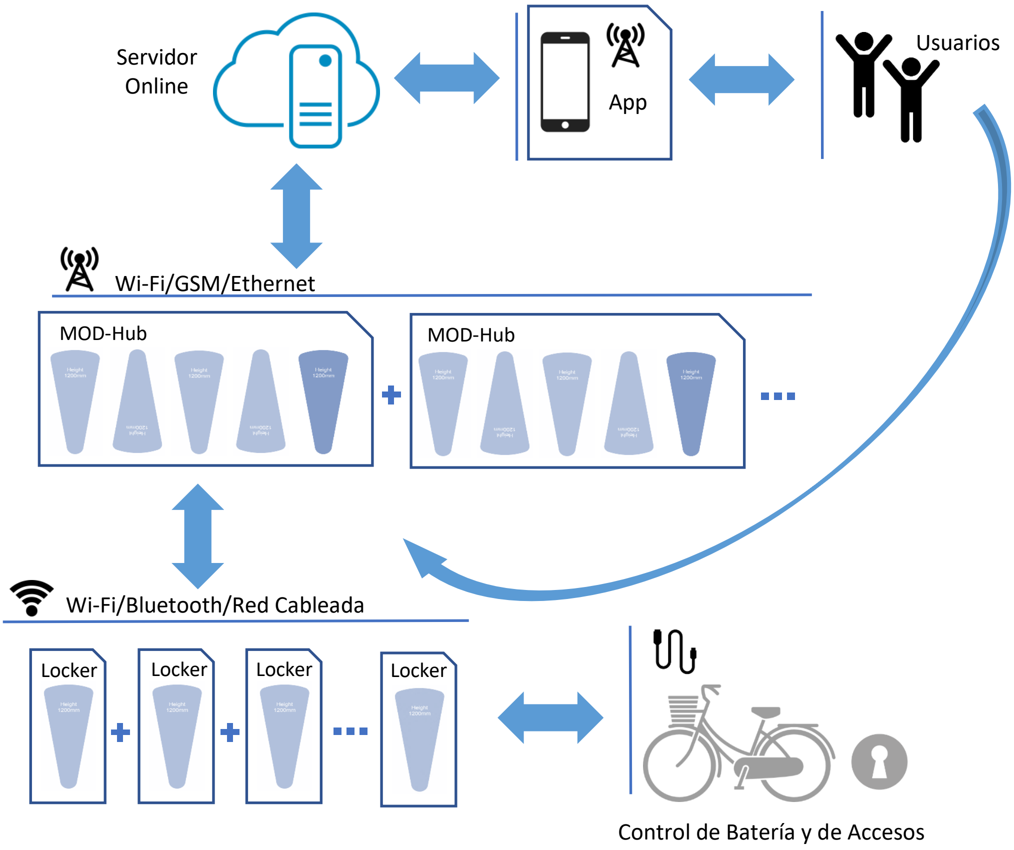

Figura 1 Arquitectura de sistema del MOD-Hub

4. Resultados

Al finalizar el trabajo se han conseguido los siguientes resultados:

- Un diseño de la geometría y las dimensiones de los módulos para aparcar las bicicletas de acuerdo con los principios de diseño que permiten total modularidad y flexibilidad en las instalaciones.

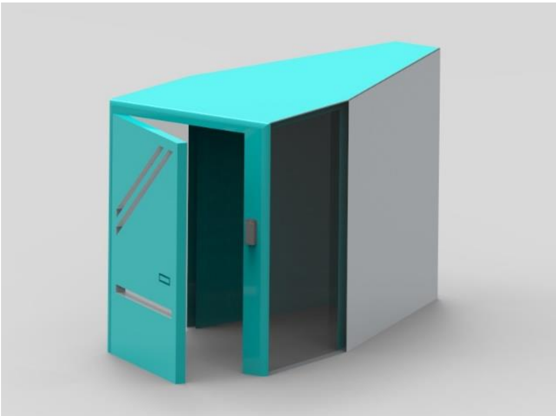

Figura 2 Modelo 3D módulo del MOD-Hub

- A partir de la arquitectura del sistema y los diseños de los módulos se han desarrollado dos placas de circuito impreso para el sistema de control:
    - Una placa de control para gestionar en los módulos individuales la automatización de las puertas, el control de la batería de la bicicleta y el control de acceso.
    - Una placa de comunicaciones para cada MOD-Hub compatible con comunicaciones vía red móvil o Wi-Fi para conectar con el servicio en la nube cada uno de los dispositivos.

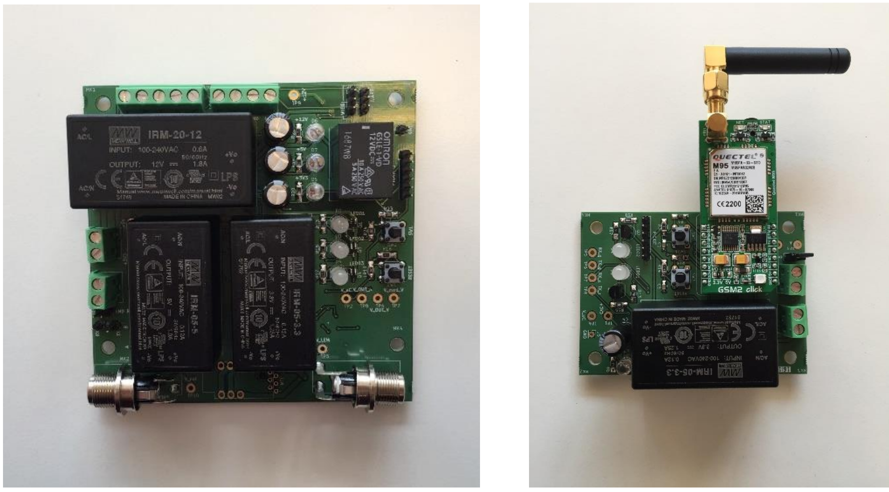

Figura 3 Placas de circuito impreso desarrolladas

- Además, se ha realizado un estudio detallado de los requisitos para hacer del MOD-Hub una instalación energéticamente autosuficiente valorando distintos modelos y alternativas usando energía solar.

5. Conclusiones

En definitiva, este proyecto ha contribuido a la creación de un sistema de gestión de parking para bicicletas eléctricas que pueda llegar a servir de plataforma para un cambio en el modelo de movilidad urbana mediante un sistema colaborativo y medioambientalmente limpio. De manera más concreta, se ha desarrollado el concepto de diseño de los módulos, la base del sistema de control y un estudio de gestión de su energía.

A REAL TIME E-BIKE PARKING AND SHARING MANAGEMENT SYSTEM

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Collaborator entity: S3Innovation

ABSTRACT

Electric mobility is a major driving force in the fight against environmental impact. This has even more relevance in urban transport due to the more and more urgent need for a new model for urban transit. During last year there has started a tendency to introduce bikes as a more sustainable alternative for the last mile in transport. As a response to this we have come up with a new solution, the MOD-Hub: a real time management parking and charging system for electric bikes which takes as its core design principles flexibility and connectivity through new IoT technologies.

Keywords:. electric bikes, e-mobility, parking, sharing, Smart City, IoT, transport.

1. Introduction

Electrification of transport is a global trend which is growing more and more, and it affects all kinds of vehicles opening new possibilities to have different transport models in highly populated areas such as cities. For all of this, electric bikes pose an excellent alternative for last mile trips. However, they still require a parking and charging platform for a sharing service which enables to response to demand in a dynamic way, something which can only be done with a very flexible service based in connectivity and modular approach that will result too in a low-cost solution. This way, the market uptake will be fast and effective.

2. Definición del proyecto

During this project there has been developments in various aspects of a management platform for an electric bike parking system in sharing service capable of responding in real-time to the demand thanks to a modular design and IoT technology. The product is the MOD-Hub, from which firstly was developed system architecture, then the general engineering process and the detailed design of the control and communications system. Finally, a detailed study of the energy management to make the product energetically independent was made.

3. Descripción del modelo/sistema/herramienta

Then MOD-Hub is then a series of modules to park bicycles with a modular design that allow them to be clustered into a circular or a linear layout to better adapt to the designated location. Their shape minimizes the space occupied in the scarce public space as well as makes the reallocation easy and fast. These modules create bigger groups, which through wireless connectivity can transmit data to a centralised cloud server. This will allow to have continuous monitoring and thus knowing at any time the status of the system, the state of charge of the batteries and optimise resources to improve performance. Access control is done through radio frequency identification (RFID) and through a mobile app.

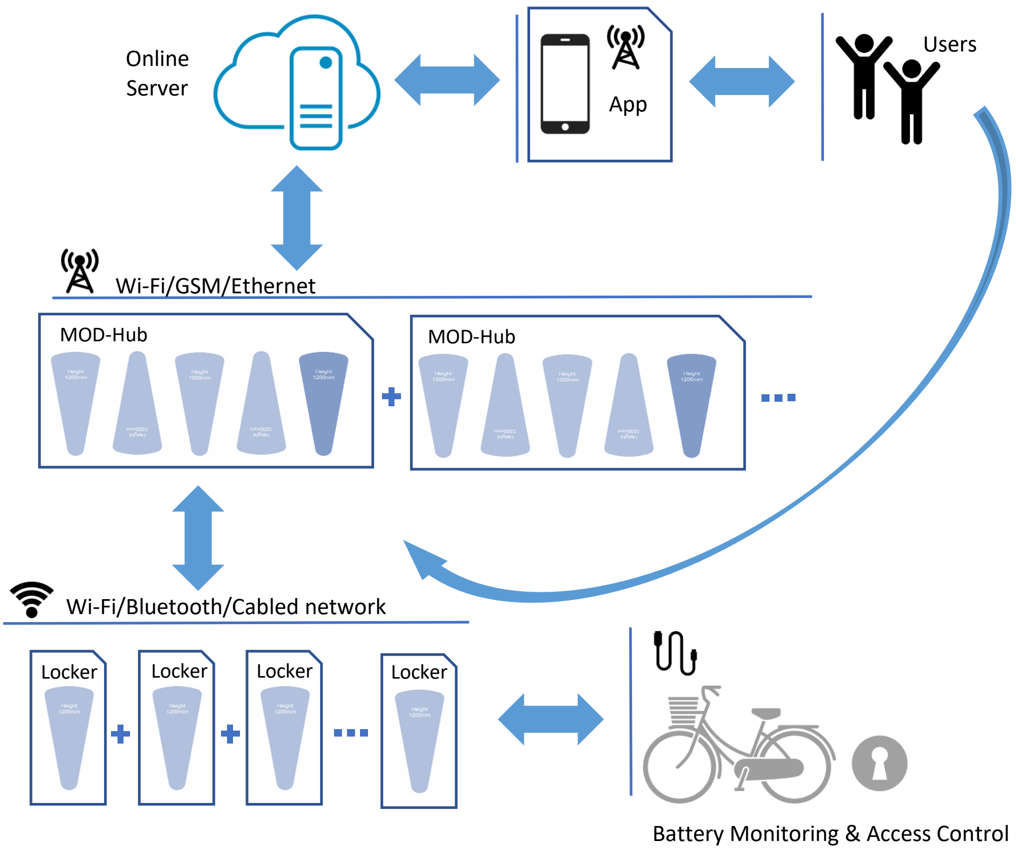

Figure 1 MOD-Hub system architecture

4. Results

At the end of the Project the following results have been achieved:

- A modular design of the geometry and the shape of the bike lockers that follows the design principles and allows total flexibility in the layout.

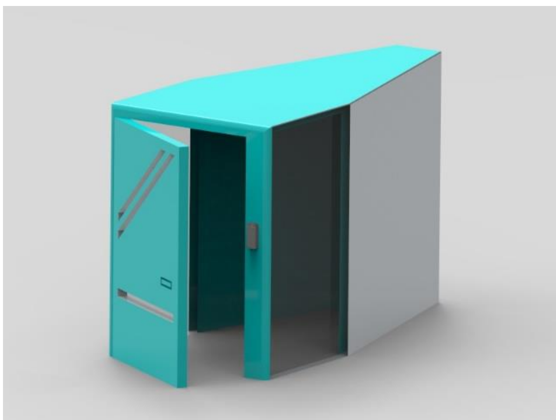

Figure 2 3D model of the MOD-Hub

- From the systerm architecture and the modules design there have been developed two different printed circuit boards for the control and communications systems:
    - A control board for every module to manage the door automation, the battery monitoring and the access control.
    - A communications board for every clues or MOD-Hub compatible with both Wi-Fi or mobile network communications to connect with the cloud server each one of the devices.

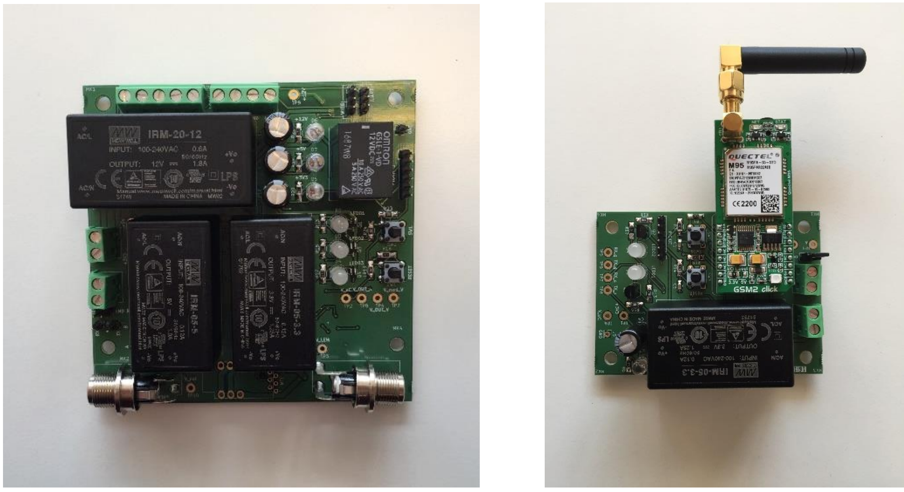

Figure 3 Developed printed circuit boards

- Additionally, there has been a detailed study of the requirements and alternatives to make the MOD-Hub energetically independent by different power supply schemes and renewable sources like the sun.

5. Conclusions

To sum up, this project has contributed to create an electric bike parking management system for a sharing service which can help to shift the current mobility model in last mile trips in urban areas into a more clean and sustainable model. More precisely, there has been developed the concept and general design of the modules, the foundations of the control system and the deep analysis of the energy management.

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CHAPTER 1. INTRODUCTION

Mobility of people and goods is a major sculptor of the urban environment, profoundly impacting the aesthetics, resiliency, sustainability of cities and the urban quality of life. Smart mobility planning within the context of smart cities may lead to a mobility future likely to differ in significant ways from today's systems [1].

Transport is still responsible for 25% of EU greenhouse gas emissions, and contributes significantly to air pollution, noise and habitat fragmentation [2]. These figures are even higher in cities so new mobility patterns and models have to be developed in order to guarantee sustainable cities [3]. But traffic congestion also affects the economy. For example, by 2004 it was estimated that traffic congestion costed the UK's economy more than £20 billion [4] while it costed the US citizens $124 billion in 2013 [5] and this cost has increased during the years as road traffic has increased quicker than road capacity .

Research and innovation activities are being carried out worldwide to support the long-term transition towards zero-emission and quieter mobility across all transport modes. Here are examples of projects currently being developed in the EU: RESOLVE project [6], EU-LIVE project [7], ESPRIT project [8] or the ELVITEN project [1]. A typical technology for zero-emissions is the electrification of vehicles. This transport electrification is happening along with the digitalisation of the mobility management, which allows to optimise resources using new software tools such as sharing systems, real-time information or advanced routing algorithms.

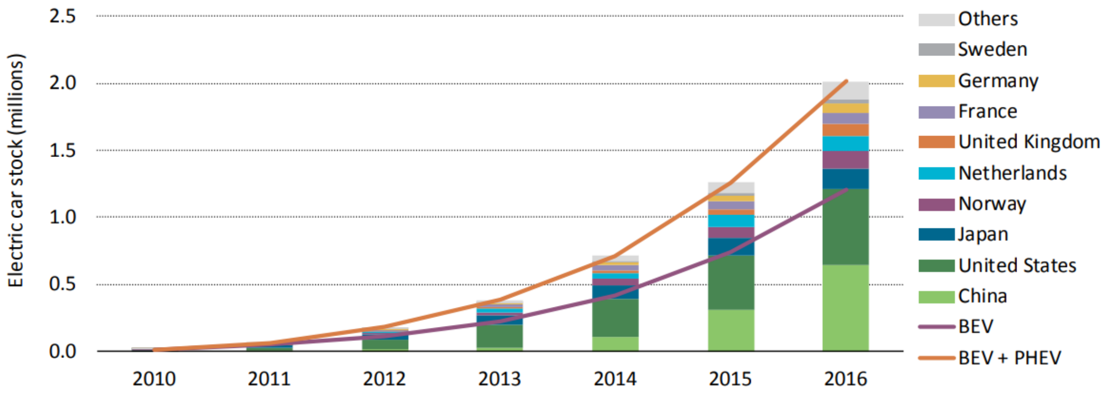


Figure 4 Evolution of global electric car stock [9]

A segment which could experience an exponential growth is the Electrified L-Category Vehicle [10] (EL-Vs) industry. In the USA about 35% of trips are of less than 5 kilometres and are covered in less than 20 minutes, being most of them cycleable [11]. Electric bicycles use less than 10% of the energy required to power a sedan for each mile traveled and emit 90% fewer pollutants per passengermile-traveled than a bus operating off peak [12]. It represents a very versatile mean of transport in the urban environment for last mile mobility, which in combination with other means of transport would build a more sustainable, clean and efficient mobility model. The increase in cycling and e-bike use would save the world a cumulative US$6 trillion between 2015 and 2030, increasing to US$24 trillion between 2015 and 2050. Thus, a future with a dramatic increase in cycling would not only reduce CO2 emissions and energy use, but would save the world an enormous amount of money [11].

Category	Bicycles	EPACS/PEDELEC	L1e
Propulsion	Muscular	Muscular + engine (eMotor)	Muscular and/or engine (eMotor)
Max Power	-	250 W	4000 W
Max Speed	-	25 km/h with eMotor assist	45 km/h with eMotor assist

Table 1 EPACS vs L1e and bicycles

Combining the use of EL-Vs, more specifically L1e category vehicles and EPACs with the new software tools creates the perfect environment to create a solution for last mile trips combinable with multimodal transport: a real-time parking and management platform for an e-bike sharing system, or as referred from now on, MOD-Hubs. The idea starts from existing systems but reconceived with a modular approach which will allow to adapt supply to the demand in real-time by means of Internet of Things (IoT) technology.

These developments are part of the Smart Cities concept which aims to create connected cities where information-based services are designed to minimize environmental impact and inefficiencies to offer the best experience to the user.

Figure 5 Smart City main elements [13]

1.1 STATE OF THE ART

Nowadays there exist a number of bike and transport sharing systems scattered in cities all around the globe. There are two main approaches: first a platform with permanent stations where users can obtain and store the vehicle; second, services in which each vehicle is permanently tracked, and users use the one they are closest to.

Some examples of them are analysed below with a comparative table at the end.

1.1.1 PERMANENT STATION SHARING SERVICES

Permanent stations act as stops, where users drop and collect bikes to move from one stop to another. They are the most common ones for city bicycle sharing and they are planned according to usage patterns. In contrast, their installation requires civil works and support from the city council, all of which makes the costs raise. The most representative are the following.

1.1.1.1 BiciMad [14]

BiciMad is the bike sharing system implemented in Madrid, Spain. Currently has 165 stations with over 4.116 docks and 2.028 electric bikes spread through the whole downtown area. It uses electric bikes with assisted pedalling (PEDELEC). Interface is made both through kiosks at stations (“totems”) and a mobile app which allows to check e-bike availability, report incidents or manage payments.

Physically, stations consist of aligned docks in the street and it was developed by Bonopark, who also supply this system for San Sebastian, Spain.

Figure 6 BiciMad charging stations

1.1.1.2 Villo Brussels [15]

With a service similar to BiciMad, but it is the official bike sharing in Brussels, Belgium. In this case, the bikes used are regular ones and interface is made solely through kiosks in stations. It counts with more than 360 stations and more than 5.000 bikes

Figure 7 Villo Brussels bike stations

This sharing system has no booking service, but service status can be checked on any browser

1.1.1.3 London Santander Bikes [16]

The London bike sharing system is one of the biggest sharing systems in Europe: 839 stations with over 13.600 bikes. It uses regular bikes and has a dedicated app to manage payments and check docking station status.

Figure 8 London Santander bikes

The technology was developed by 8D Technologies, who also supply the server technology for BIXI Montréal, Citi Bike in New York City, Capital Bikeshare in Washington DC, Melbourne Bike Share in Australia, and others. [17]

1.1.1.4 PubliBike [18]

PubliBike is a Swiss bike sharing system with a hybrid configuration. Location of stops is permanent, but bikes are not stored in bike stands, each bike has an individual lock activated with the smartphone. All the process is carried within a mobile app: look up for bike availability in stations and bike unlocking. It uses both regular bikes and e-bikes and has 390 stations across Switzerland managing 2350 regular bikes and around 1420 e-bikes.

Figure 9 PubliBike Switzerland bikes

1.1.2 NON-PERMANENT LOCATION SHARING SERVICES

In this approach the user locates through the platform the nearest vehicle and uses it while it is being remotely monitored by the operator. It is more commonly used by electric motorbikes and car sharing services, however, as it is shown below there are exceptions.

1.1.2.1 Mobike [19]

A Chinese bike sharing platform present in several cities all around the globe such as Manchester, Santiago de Chile, Singapore, Shanghai… The bikes are designed to not need maintenance for 4 years, to be lightweight easy to ride and with anti-puncture tyres. The system works through a mobile app which connects to the bike lock through Bluetooth. Reading a QR code unlocks the bike and starts the ride. The bikes can be parked anywhere within the limits stablished in the app by the company.

Figure 10 Mobike sharing system

1.1.2.2 Car2Go [20]

Car2Go is an electric carsharing service in Europe, North America and China. It uses electric Smart vehicles. With this service users book a car parked in the street, they open and start it with their phone and use it within the limits. When finished, users just hop off and close the car again with their phones. Users are charged for the time they use the vehicle.

Figure 11 Car2Go vehicle

1.1.2.3 eCooltra [21]

This is a Spanish Electric motorbike sharing system. It uses electric scooters that can be booked from a mobile app. The service only charges for the amount of time the scooter is used and can only be parked within certain limits. At the moment, the service is available in Madrid, Barcelona, Lisboa and Rome.

Figure 12 eCooltra electric scooters

From this analysis we can extract that there is not a suitable alternative for the market which is compatible with electric bikes, offers a sufficient degree of protection to the vehicle, can adapt dynamically to the demand and is affordable both for deploying it in a significant scale and to the user. Therefore, it is considered necessary a new solution with a different approach the problem. A comparison between all of the alternatives can be seen in Table 2.

Service	**BiciMad**	**Villo Brussels**	**London Bikes**	**Publi Bike**	**Mobike**	**Car2Go**	**eCooltra**	**MOD-Hub**
App	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Installation cost	High	High	High	Medium	Low	Very high	Very high	Low
Cost to the user	Low	Low	Low	Low	Low	High	High	Low
Adaptability	Low	Low	Low	Medium	Very high	High	Very high	Very high
Electric vehicle	Yes	No	No	No	No	No	Yes	Yes
Service expansion time	Slow	Slow	Slow	Slow	Quick	Quick	Quick	Quick
Security of the vehicles	Medium	Medium	Medium	Medium	Low	High	High	High

Table 2 State of the art comparison

1.2 MOTIVATION OF THE PROJECT

Sharing platforms for intermodal transport is a growing market. More and more cities are including in their streets a sharing bike service. However, only a few providers are present and the variety of offered services is still very limited. So as a result, a solution which has a dynamic approach to the demand, which is user centred and adaptable to the consumer needs is proposed.

This approach, more than ever, is possible thanks to the quickly rising IoT technology that allows to implement very accessible solutions to problems which used to be very complex by offering ready to use market solutions.

Another aspect that will be considered in this project is the Low Energy Computing by using energy efficient devices and effective control algorithms.

1.3 PROJECT OBJECTIVES

As a whole, the goal of this project is the creation of the first version of an electric bike parking and sharing management service. In case, because of time limit it was not possible to achieve a ready to sell version at least create solid foundations for further development.

- Define the technical specifications of the MOD-Hub and the set the desired functionalities.
- Create a design for the lockers.
- Define manufacturing requirements for the product.
- Develop a control board for the metering of the state of charge of the e-bikes and for the access control management.
- Develop a communications board for the MOD-Hub capable of connecting to an external server.
- Define the basic requirements for the IT platform for further developments in order to complete the product functionality.

1.4 WORKING METHODOLOGY

For the working plan there will be three main phases in the development of the project:

- Phase I: Concept definition. During this phase the technical specification and requirements of the product will be set in order to have a clearer view for the design phase.
  This phase will happen during months 1 and 2 of the project.
- Phase II: Design. In the next phase a design of the system will be carried from a more general view to every specific subsystem. This will have two sides:
  - Mechanical design. This includes the lockers for the e-bikes, the locking mechanisms, the enclosures for the control equipment, the linkage between the lockers or the bike support structure.
  - Electronical design. The locking system, communications and monitoring will be developed to integrate with the mechanical part.

  This phase will take place from months 2-5
- Phase III: Action. In the last phase the design will be implemented and tested. All the systems will have to be tested separately and then jointly to be able to check the performance in a more accurate way.

Phase II and phase III will be carried in parallel once a certain level of design has been achieved. This will also mean that iterations will have to be made to improve the system progressively. Additionally, as the system is separated in parts which have a clear dependence, it will make the implementation a dynamic process.

To have control over the different milestones of the development the task management tool Trello will be used. It is an internet base portal where there are cards which are customisable to include tasks, checklists, deadlines and comments for each one of them. Additionally, the team will hold weekly meetings to follow up the project progress and validate the decisions made in every step.

Task	M1	M2	M3	M4	M5	M6
Concept definition						
Mechanical design						
Electronic design						
Implementation						
Testing						

Figure 13 Project Gantt Chart

1.5 RESOURCES USED

Resources that will be needed

For this project both physical and software tools will be necessary:

- **Hardware** tools to make electrical measurements, rework on printed circuits and for electronic handling:
  - Oscilloscope.
  - Computer.
  - Electronic component welder and tools.
  - Multimeter.
  - Cables of different sizes.
- **Software** programs such as:
  - Microsoft Office: Excel, Outlook and Word.
  - Opensource electrical CAD software: KiCAD.
  - Task management: Trello.
  - Teleconference program. Skype
  - Communication debug program: CoolTerm
  - 3D-CAD design program: Solid Edge ST4
  - MCU integrated development environment (IDE) MPLABX
  - Draw.io for the creation of diagrams.

Figure 14 SW tools for the project

CHAPTER 2. CONCEPT & DESIGN

2.1 INTRODUCTION

In this chapter it is defined the framework for the development of the MOD-Hub as well as the design paradigms and the general architecture. This framework is essential as it is the principles from which the functionalities and characteristics of the product are derived.

2.2 DESIGN PARADIGMS & CONCEPTS

Four main principles have been taken into consideration for the design:

- **Modularity**. In order to be able to adapt the parking allocations to the demand in real-time the design must ensure an easy assembly that can be adapted to the environment.
- **User friendliness.** It is important that the system is easy to use and intuitive to provide a good user-experience.
- **Costless**. The manufacturing and the maintenance of the modules must have low costs to ensure an effective market uptake and a successful business model.
- **Connected**. Connectivity is a key factor to create a dynamic and adaptable system. It will also allow the system to be part of the Smart City concept by providing cities with useful data to optimise the resources and services.

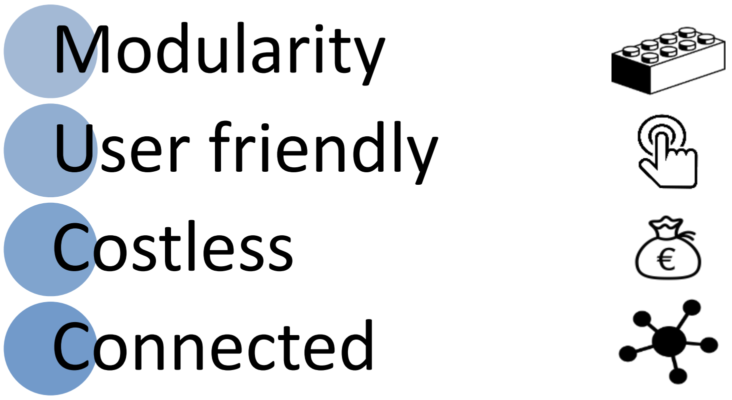


Figure 15 Design principles

The goal then, is to provide the user a user-friendly experience with a low-cost product that is extremely flexible by being able to react to the demand in real-time through advanced connectivity capabilities using Internet of Things (IoT) technology.

Following the modularity approach, every hub is the essential unit of the system and it is combined with other hubs creating groups that work coordinated and connected to a cloud service. Through this modular capability, easy transport of hubs would allow to reallocate them easily according to the demand analysis and user requirements.

Any of this would be meaningless if the cost of the system was higher than existing systems, that's why through better design and thinking out of the box a solution has come up that reduces significantly the costs resulting in a more versatile product with less required investment.

In order to achieve this, we make use of a new approach to connectivity and off-the-shelf technology that allows us to quickly develop and integration at a lower cost combined with custom hardware to perfectly meet our requirements.

2.3 ELECTROTECHNICS REGULATION ANALYSIS.

It is important to know the legal framework in which the MOD-Hub will be placed. Rules applied have direct consequences in the design process, so they must be very clear. First of all the standardization organisms to look for regulation are organised as follows:

	General	Electrotechnics
Global	ISO	IEC
European Union	CEN	CENELEC
Spain	UNE	REBT
Italy	UNI	CEI

Table 3 Standardization organizations

A compilation of the standards that apply in all the world for charging electric vehicles has been extracted from the Italian law and is shown in the following figure:

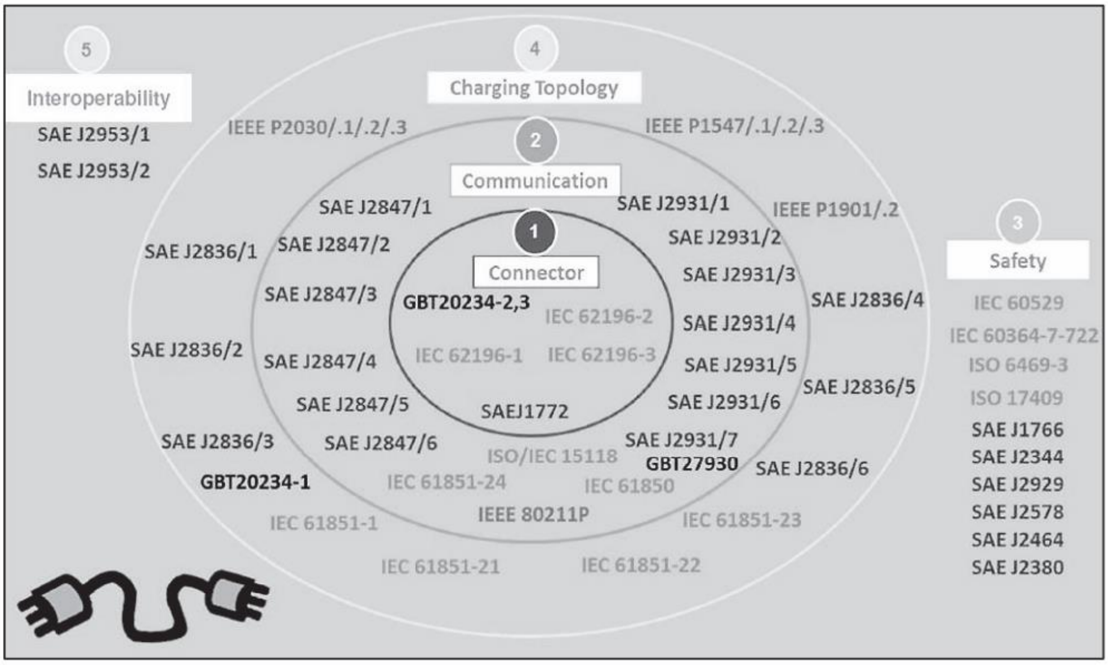


Figure 16 Global standards for electric vehicle charging infrastructure

2.3.1 INTERNATIONAL REGULATION

The electrotechnics standards that apply for this kind of product are the ones valid in each of the countries to be installed in. However, in the EU national regulations in this field are all derived from the International Electrotechnical Commission (IEC) standards. The sections of the IEC that could apply in this case are:

- IEC 60364-7-722:2015 Low-voltage electrical installations - Part 7-722: Requirements for special installations or locations - Supplies for electric vehicles. This standard provides with the normative for the circuits that are intended to supply energy to electric vehicles. [22]
- IEC 60364-7-722:2009 Low-voltage electrical installations - Part 7-717: Requirements for special installations or locations - Mobile or transportable units. This standard is aimed at any mobile or transportable structure with electric circuits in it. However, there is an exception in this standard for structures that have circuits which are aimed for automotive purposes. So, if we consider e-bike infrastructure as so, it has no validity. [23]

2.3.2 SPANISH REGULATION

In Spain exists the Low Voltage Electrotechnics Normative (REBT) open to the public and it is very precise about these installations. The applicable standard is the ITC-BT-52 [24] for infrastructure for electric vehicle charging.

2.3.3 ITALIAN REGULATION

In Italy the regulation on electrotechnics is created by the Italian Electrotechnics Commission (CEI). Currently it is valid the law: Legge 7 agosto 2012, n. 134 from the Piano nazionale infrastrutturale per la ricarica dei veicoli alimentati ad energia elettrica - PNire (National plan for electric vehicle recharging infrastructure) [25]. The exact technical standards that affect the charging facilities are the following:

- Norma CEI 312-11: Prescrizioni di sicurezza per stazioni di ricarica per veicoli elettrici stradali

- Norma CEI EN 61851-1: Ricarica conduttiva dei veicoli elettrici – requisiti generali

2.3.4 CONCLUSION

In Europe all electrotechnics regulation is derived from the IEC standards so: either the IEC standard can be applied or any country's specific regulation, but this last option would require afterwards a compatibility check among target markets. Conflicts between national regulations should be minor considering that all standards are derived from the same source.

2.4 GENERAL ARCHITECTURE

In this section the desired characteristics and the general architecture of the system are established. They will serve as a guideline during the entire process and will help to start setting the priorities.

The MOD-Hub is the central piece of a complete e-bike sharing and booking system. This requires the system's control to be centralised, which is only possible by operation through a cloud service. The architecture of the complete system is shown in Figure 17 and it would count with the following functionalities:

- E-bike charging and status monitoring.
- Booking service of bike for the users through a mobile app.
- Centralised access control.
- Real-time system usage monitoring and e-bike allocation management.

For this work, the basic engineering design of the whole and the detail engineering of the control and communication systems of the lockers have been developed. There is a door open for future developments in order to finish the product for its market introduction, which is analysed in CHAPTER 8.

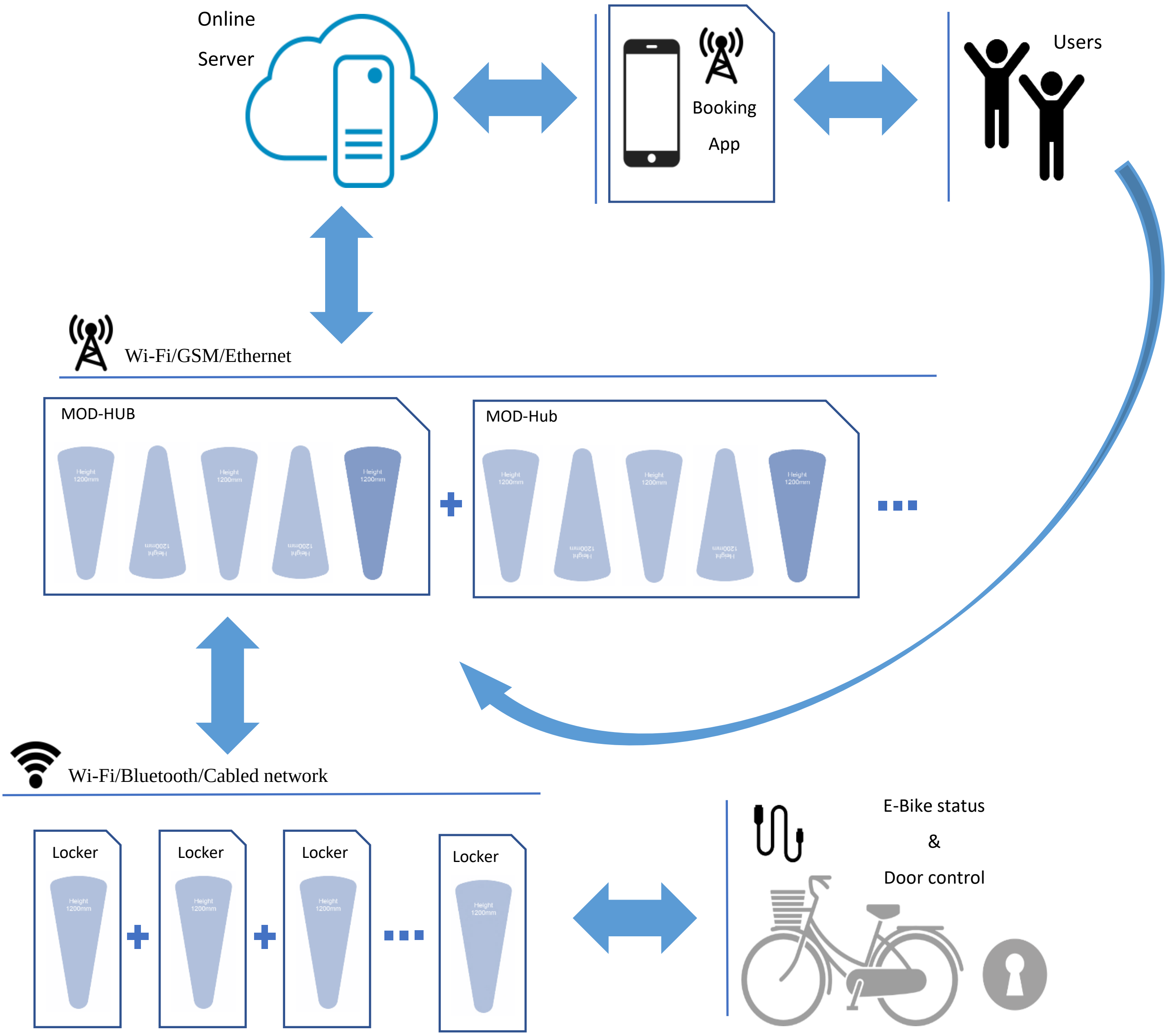


Figure 17 General system architecture

2.5 MOD-HUB'S CONNECTIVITY LEVELS

It is important to define what is the level of integration and connectivity desired for the product to focus the efforts. The development will be carried always with a holistic view of the product and as there is a clear differentiation of products according to the connectivity as it is a key factor for functionality and design.

- Level 0 – Manual lockers. In the first stage, the lockers are manually operated:
  - Keys are used to open the lockers.
  - No door control or monitoring.
- Level 1 – Independent smart lockers. Each locker has its own control system isolated from the rest. Functionalities of each locker would be:
  - Electronic access control with RFID cards or code.
  - Automatic door lock.
  - Monitoring of the e-bike status locally in each locker.

  As each locker has no interaction with the outside and no supervision is possible to control whether each user only has one bike or to know how many bikes are available in each hub.
- Level 2 – Smart hubs. Lockers are interconnected conforming a MOD-Hub. There exists a unit which has a centralised managing system for the group of lockers. The MOD-Hubs are isolated from the rest of the system.
  E-bike monitoring can be made from the central module which would send the commands and gather all their information from each individual locker.
  Only one user interface implemented in the managing module (screen).
- Level 3 –MOD-Hub. MOD-Hubs are connected through a centralised system such as an online server allowing:
  - Use of a booking system for the e-bikes from either an app or a MOD-Hub.
  - Centralised information of e-bikes and MOD-Hubs status to make decisions based on the overall state of the system in real-time.

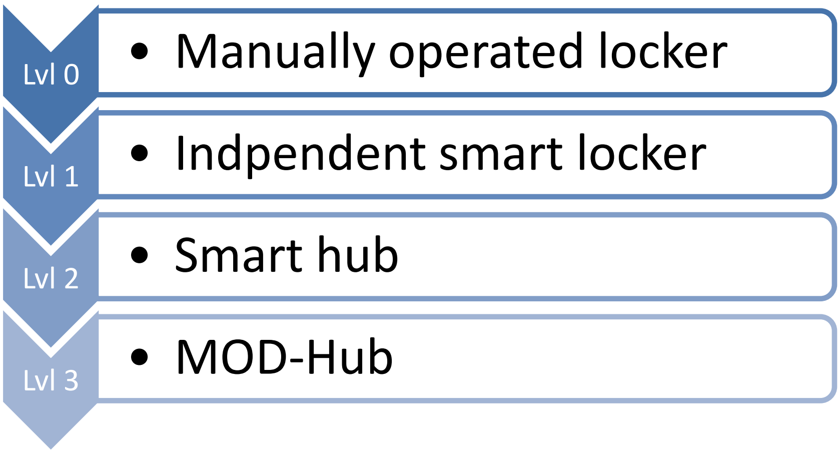


Figure 18 Connectivity levels integration

The aim of the MOD-Hub is to provide full connectivity among modules and locations to have full control and capacity over every element. If this achieved, the product will have a strategic advantage in comparison to similar products in the market to become industry leaders.

2.6 SUBSYSTEMS

In a complex system such as the MOD-Hub the operation of many subsystems simultaneously is the biggest challenge. A careful development always having a holistic view will be determinant to achieve a design that performs to the required level. Considering this, firstly it is important to define each one these subsystems or subparts to then, analyse the implications of the integration between them and define the design specifications. The main subsystems identified are the following:

2.6.1 MECHANICAL DESIGN

This subsystem is the physical layer of the MOD-Hub and it includes the shape design, the materials for construction, the layout of the elements inside the lockers, the bike position locking system, the connection between modules and other general constructive requirements.

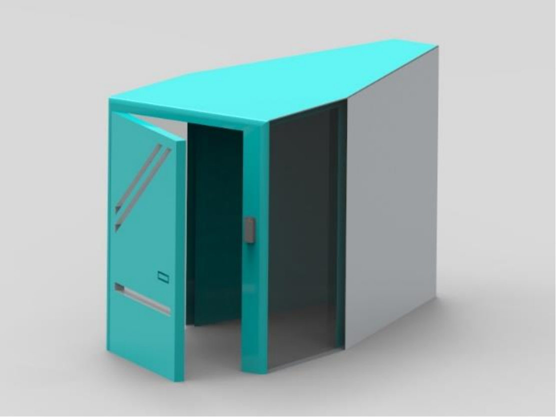


Figure 19 MOD-Hub geometry 3D model

2.6.2 CONTROL SYSTEM

Control is a key part for the product. It will determine the user experience success and the capabilities of integration into different platforms. The control system is in charge of communications, access control or battery monitoring.

There were two possible approaches for the control system: on the one hand, using generic purpose industrial equipment like programmable logic controllers (PLCs); and on the other hand, designing and developing custom made equipment. These two alternatives offer different capabilities which may affect the functionalities and cost of the final product.

2.6.2.1 Industrial automation equipment

The use of industrial automation equipment would reduce the development to programming the logic, as this kind of technology counts with standardised actuators and sensors, simplifying the whole process.

In contrast, it counts with some drawbacks with regard to the design paradigms of the product. Firstly, the cost of PLCs is more than 5 times higher than the cost of custom made equipment. This is because PLCs are designed to operate in industrial environment, so they have very restricted standards. Secondly, their computing power is limited, as they are used to control simple tasks, so they need of different modules and add-ons to increase that operating capacity. Finally, their flexibility is constrained by the available technology on the market and the rigid structure of their programming.

Figure 20 PLC example

This technology poses an alternative which offers a quick development environment using off the shelf components that are highly standardised and which work in a "plug and play" mode. However, because of its higher cost and reduced flexibility, it was discarded as the main option.

2.6.2.2 Custom equipment

A totally different approach is to develop dedicated hardware and software for the purpose of the MOD-Hub. This requires printed circuits(PCB) design, component selection and a higher level of system definition. This approach has the advantage that while the integration process may require more effort, the cost of the product once totally designed sinks due to scale economy. Moreover, it offers total flexibility in the functionalities and in the programming, which are a key principle for the product.

Taking advantage of current progress of Internet of Things (IoT) technology, which offers solution to many of the challenges posed, would make the MOD-Hub smarter and able to provide a better user experience.

For all of this, it was decided to develop custom made hardware so a low cost, highly flexible and reliable solution can be delivered.

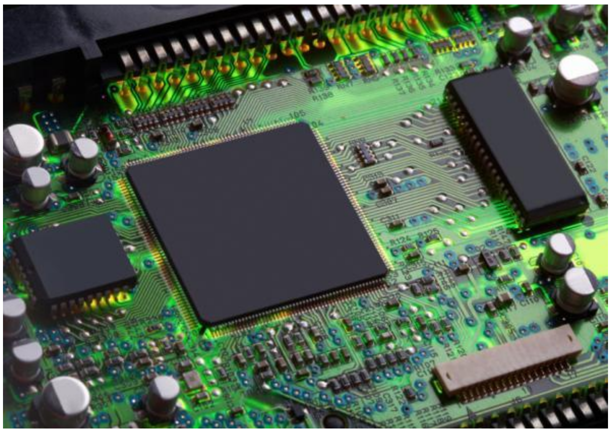


Figure 21 A PCB with a microcontroller unit

The control subsystem oversees the door access control and battery monitoring. It has a very big interdependence with the communications system as they directly share elements. A custom circuit control board has been developed for the MOD-Hub. This circuit is an all integrated solution which only has as inputs a generic 230V power supply, the e-bike charger, the door electric mechanism and an tag/card reader for access control.

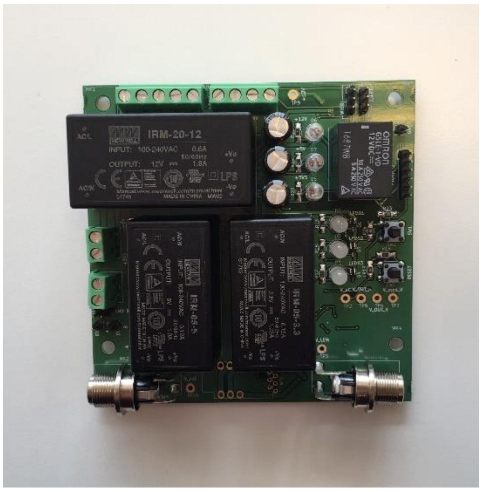


Figure 22 Control board v0.1

The board is designed to be able to manage a set of tasks and requirements which include:

- Battery monitoring.
- Control of the battery power flow.

- Door opening with any kind of electric mechanism.
- Support for a Radio Frequency Identification (RFID) reader with both WIEGAND protocol or serial interface.
- MOD-Hub local communications network with RS-485 standard.

2.6.3 COMMUNICATIONS SYSTEM

The communications system is in charge of making all of the parts of the MOD-Hub to send information and exchange messages. These messages include status updates, requests for service or orders. Following the same approach as with the control system, a custom-made communications board has been developed. This board counts with a connector to plug in different external communication modules depending on which type better adapts to the conditions of the location for the MOD-Hub. These modules have their own APIs to have a quick and reliable integration.

Figure 23 Communications board v0.1 with GSM module

The communication architecture of the MOD-Hub is based on both wired and wireless communications: the modules send messages to the gateway through a cabled network, and the communications module communicates with the cloud server through mobile or Wi-Fi communications.

2.6.4 ENERGY MANAGEMENT SUBSYSTEM

Energy is an important matter for the MOD-Hub so in order to have full energetic independency, a study of alternative power supply schemes has been made, mainly studying solar panels viability and the different alternatives for the system from products in the market.

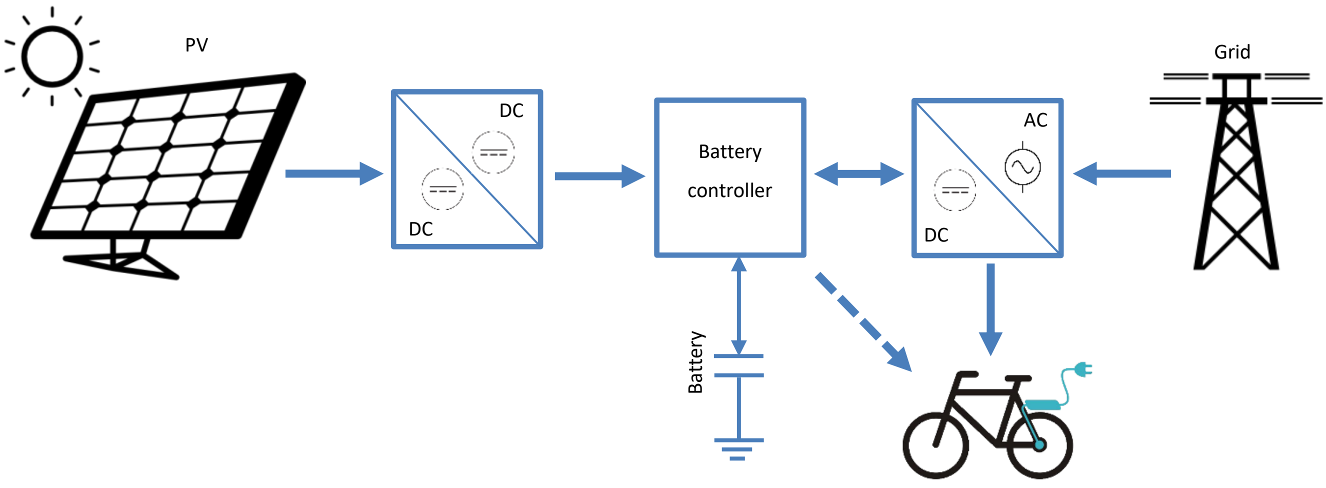


Figure 24 Hybrid PV system with grid support

CHAPTER 3. MECHANICAL DESIGN

3.1 GENERAL DESIGN

From early concept the aim was to create a modular design which would make the hub adaptable to the demand in real-time. This means that the MOD-hub modules must be transportable and attachable between them. Additionally, to make the system anti-vandalise the bikes must be completely sheltered, and bikes must be accessible for all type of citizens, so they need to be easy to release and locked-in.

3.2 SIZES AND SHAPES ANALYSIS

Taking all of this into account, different shapes and sizes are analysed: rectangular shaped lockers would be the simplest ones, but they take more space and are limited to linear configuration. Circular shapes are not adequate because they take too much space and are not modular. In contrast, triangular shaped lockers are considered to be more suitable: they can be arranged into both linear and circular topologies, they occupy approximately the same space than the rectangular shaped ones and have more possible combinations.

In the following figure, the main dimensions of triangular and rectangular locker designs are defined.

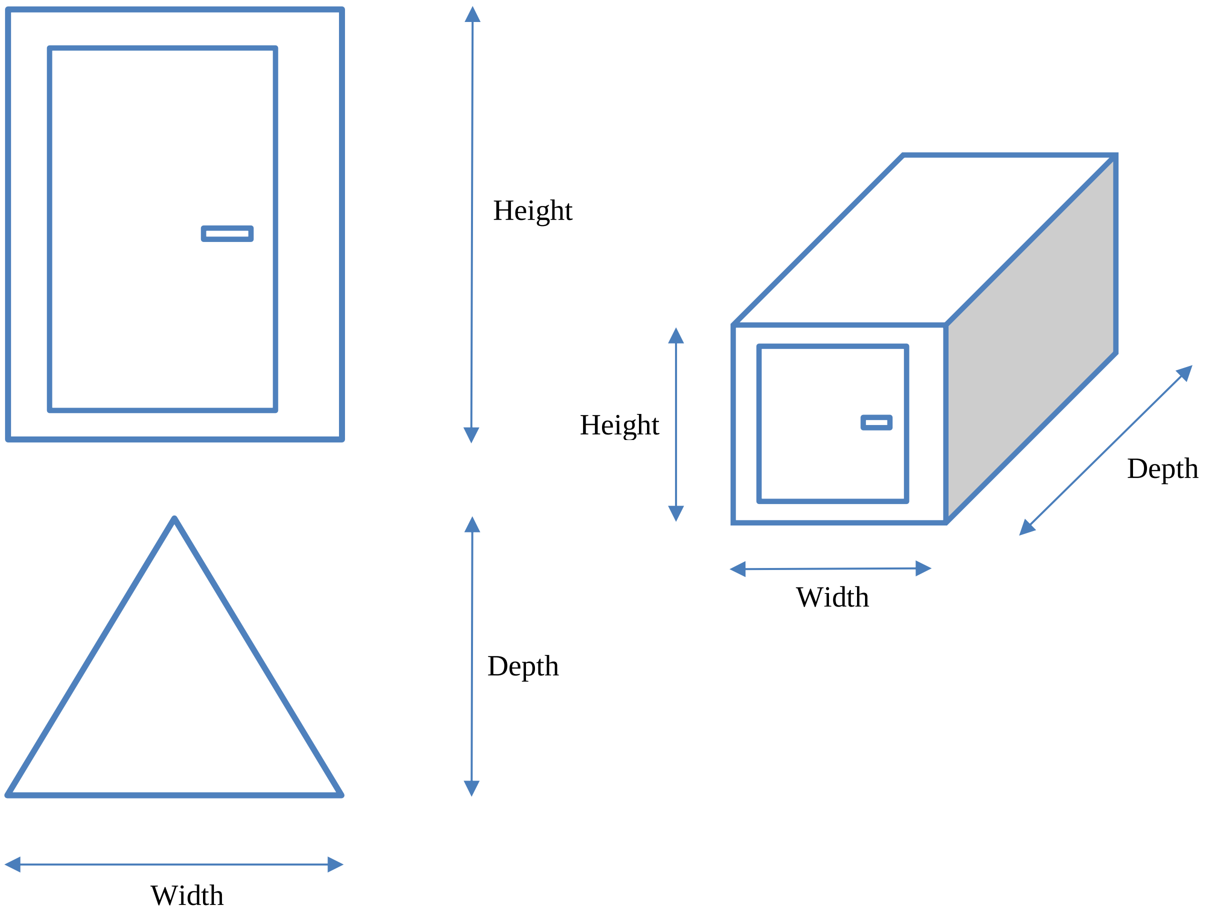


Figure 25 Rectangular & triangular models

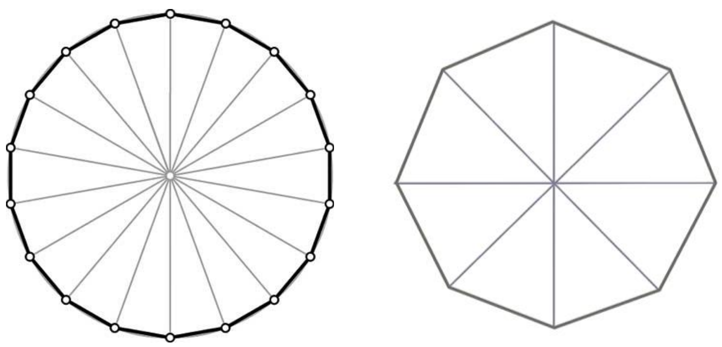


Figure 26 Triangular design modular configurations

Furthermore, bikes could be placed semi-vertically inside the locker to use less space. However, the inclination cannot be excessive to ensure that anyone can be able to put up or down the bike. As for this, three configurations are explored: a zero degree, a thirty degree and a forty-five-degree.

An additional parameter of the triangular shape is the angle of the triangle which will define how many portions will fit into the circular configuration. As the bike will be introduced in forward orientation and because of the triangular shape of the locker, the handlebar will need a minimum distance to the vertex of the module to fit in, which depends on the angle of the module. As there can be unused space from the wheel to the vertex, a variation in the design can was made in the form of a triangle with on flat point, saving additional space. This space saving would only affect the linear configuration, as for the circular one, the total diameter would remain unchanged.

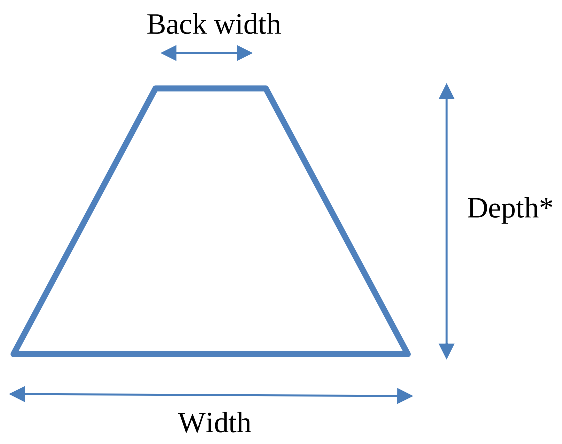


Figure 27 One flat vertex triangle design configuration

Figure 28 One flat vertex configurations

Then, an more advanced version was developed. In order to reduce the unused space a polygonal shape was proposed and analysed. This shape reduces even more the space required for each locker while maintains the modular capability. The additional advantage of this design is that there is more freedom to choose the width of the front part.

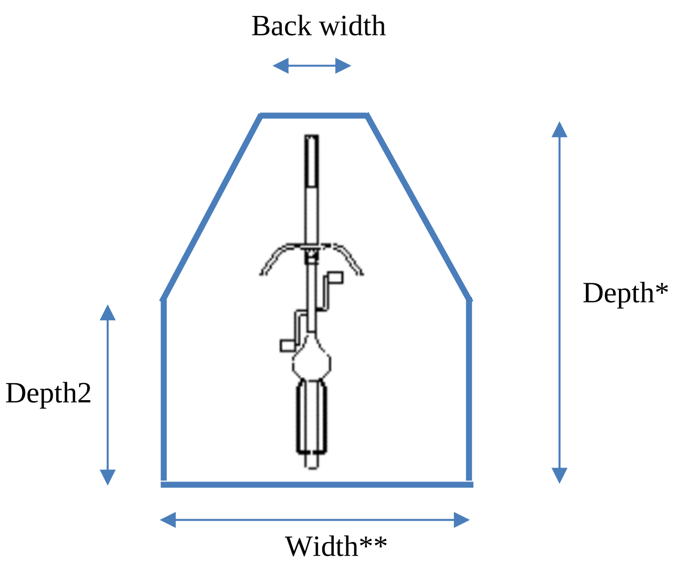


Figure 29 Three flat vertex design

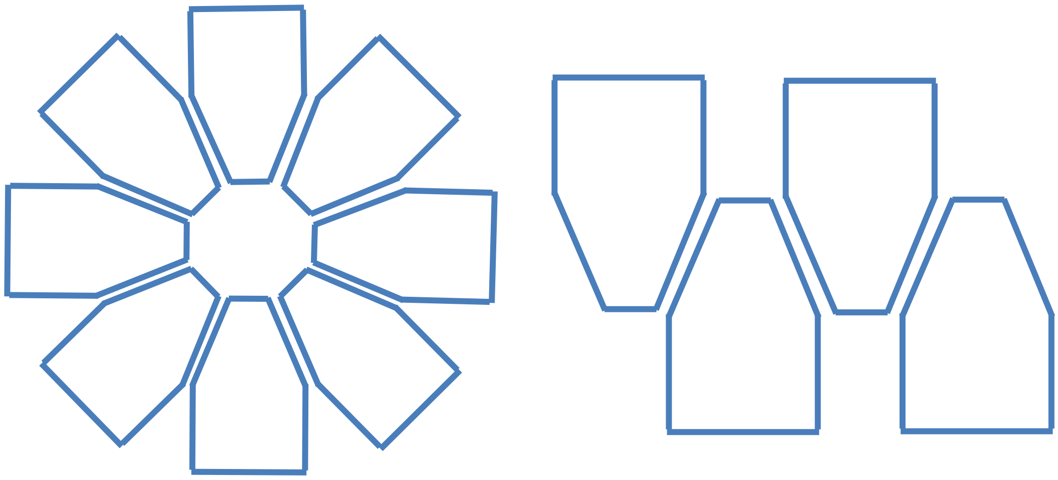


Figure 30 Modular capability of the three flat vertexes model

A comparison between rectangular and both triangular designs has been made with different configurations. For this comparison, a bike with the dimensions described in Table 4 was considered:

Bicycle	
Length (cm) - L_{bike}	182
Height (cm) - H_{bike}	111
Width (cm)	70
Handlebar2Wheel (cm)	60
Wheel radium (cm) - r_{wheel}	66

Table 4 Bycicle size consideration

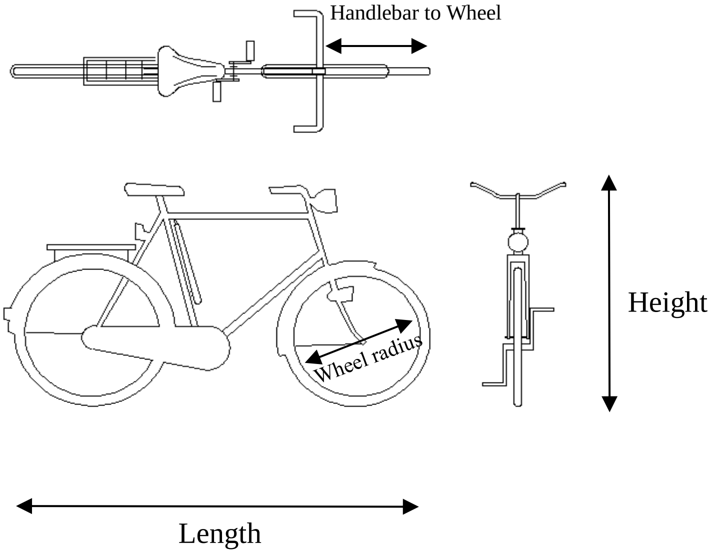


Figure 31 Bicycle model dimensions

3.2.1 TRIANGULAR PARAMETER CALCULATIONS

The dimensions and parameters of the modules are calculated as follows. Bear in mind that the number of modules for the circular configuration will affect the rest of the parameters.

- Slope angle:

$$\alpha = [0°, 30°, 45°]$$

- Angle of the topology. Depends on how many modules are required t on the circular configuration:

$$\beta = \frac{360°}{Number\ of\ modules}$$

- Minimum distance of the handlebar to the vertex of the module to have enough space:

$$Handlebar\ to\ wall = \frac{Handlebar}{2} \cdot \frac{1}{\tan\left(\frac{\beta}{2}\right)}$$

- Depth:

$$D = (L_{bike} - 2 \cdot r_{wheel}) \cdot \cos\alpha + 2 \cdot r_{wheel} + Handlebar\ to\ wall - Handlebar\ to\ wheel \cdot \cos\alpha$$

- Height: Will depend on how to position the e-bike in the locker. Two cases have been analysed:
    - CASE I: The whole bike is in a ramp.

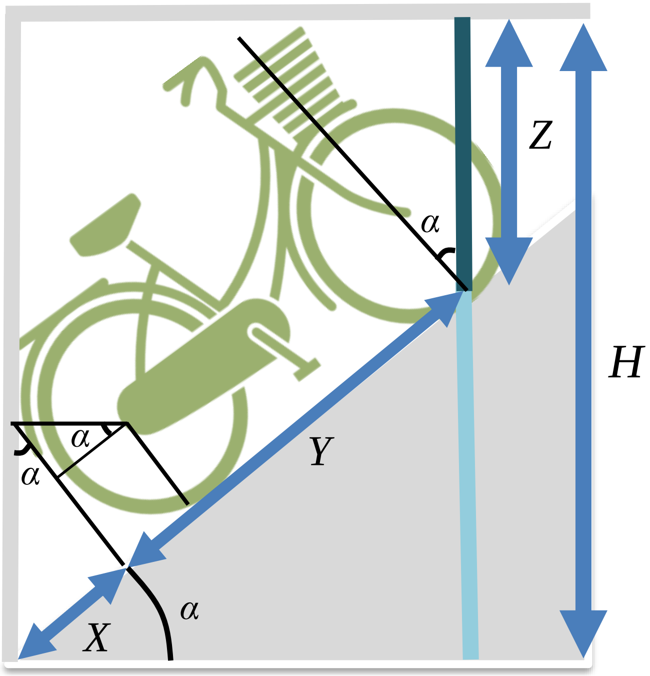


Figure 32 Height calculation bike position I

$$X = (r_{wheel} + r_{wheel} \cdot \sin\alpha) \cdot \tan\alpha$$

$$Y = L_{bike} - r_{bike}$$

$$Z = h_{bike} \cdot \cos\alpha$$

$$H = (X + Y) \cdot \sin\alpha + Z$$

$$H = \left((L_{bike} - r_{wheel}) + (r_{wheel} + r_{wheel} \cdot \sin\alpha) \cdot \tan\alpha\right) \cdot \sin\alpha + h_{bike} \cdot \cos\alpha$$

- CASE II: The bike is partially placed on the ground.

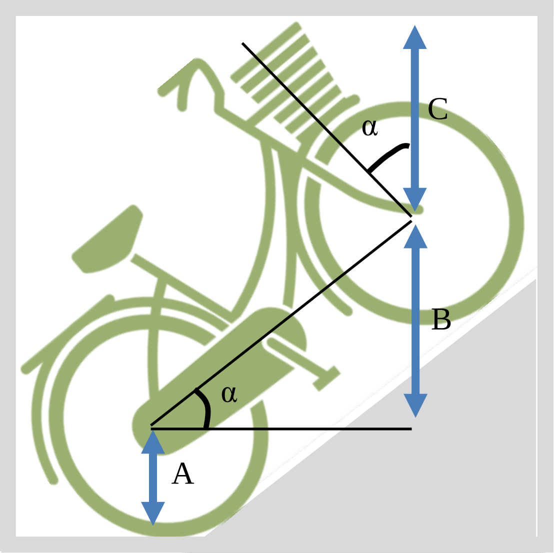


Figure 33 Height calculation bike position II

$$A = r_{wheel}$$

$$B = (L_{bike} - 2 \cdot r_{wheel}) \cdot \sin\alpha$$

$$C = (h_{bike} - r_{wheel}) \cdot \cos\alpha$$

$$H = A + B + C = r_{wheel} + (L_{bike} - 2 \cdot r_{wheel}) \cdot \sin\alpha + (h_{bike} - r_{wheel}) \cdot \cos\alpha$$

In this case, **the results are lower than in case I. So this onfiguration will be used**.

- Width. Depends on the depth of the module and the chosen topology:

$$W = \frac{2 \cdot D}{\tan\left(\frac{180 - \beta}{2}\right)}$$

3.3 CONFIGURATION COMPARISON

The results obtained for the most representative configurations for the triangular design are in the following table.

TRIANGULAR & ONE FLAT VERTEX										
Sides	**Slope angle (°)**	**Depth (cm)**	**Width (cm)**	**Height (cm)**	**Depth* (cm)**	**Handlebar-Wall (cm)**	**Volume (m^3)**	**Volume* (m^3)**	**Area (m^2)**	**Area* (m^2)**
	0	187,6	216,6	117,0	187,0		4,9	4,9	4,1	4,1
6	30	180,1	208,0	164,5	179,5	48,2	6,4	6,4	3,7	3,7
	45	171,2	197,7	176,2	170,6		6,2	6,2	3,4	3,4
	0	211,5	175,2	117,0	187,0		4,5	4,4	3,7	3,3
8	30	204,0	169,0	164,5	179,5	84,5	5,8	5,8	3,4	3,0
	45	195,1	161,6	176,2	170,6		5,7	5,6	3,2	2,8
	0	257,6	151,3	117,0	187,0		4,7	4,4	3,9	2,8
12	30	250,1	146,9	164,5	179,5	130,6	6,2	5,8	3,7	2,6
	45	241,2	129,3	176,2	170,6		5,6	5,2	3,1	2,2
	0	291,7	133,1	117,0	187,0		4,6	4,1	3,9	2,5
15	30	284,2	129,7	164,5	179,5	164,7	6,2	5,4	3,7	2,3
	45	275,3	117,0	176,2	170,6		5,8	5,0	3,2	2,0
	325,5	121,7	117,0	187,0	325,5		4,7	3,9	4,0	2,3
18	318,0	118,9	164,5	179,5	318,0	198,5	6,3	5,2	3,8	2,1
	309,1	109,0	176,2	170,6	309,1		6,1	4,9	3,4	1,9
	0	348,0	116,1	117,0	187,0		4,8	3,8	4,0	2,2
20	30	340,5	113,6	164,5	179,5	221,0	6,5	5,1	3,9	2,0
	45	331,6	105,0	176,2	170,6		6,2	4,8	3,5	1,8
	0	370,4	111,7	117,0	187,0		4,9	3,8	4,1	2,1
22	30	362,9	109,4	164,5	179,5	243,4	6,6	5,1	4,0	2,0
	45	354,0	101,8	176,2	170,6		6,5	4,8	3,6	1,7

Table 5 Triangular configurations comparison

As for the rectangular design the results obtained are the following:

RECTANGULAR					
Slope angle (°)	**Depth (cm)**	**Width (cm)**	**Height (cm)**	**Volume (m^2)**	**Floor Area (m^2)**
0	202,0	80,0	117,0	189,1	1,6
30	177,6	80,0	164,5	233,8	1,4
45	148,7	80,0	176,2	209,6	1,2

Table 6 Rectangular configuration comparison

For the three flat vertex triangular configuration the results are shown in

TRIANGULAR & THREE FLAT VERTEXES											
Sides	**Slope angle (°)**	**Width (cm)**	**Width** (cm)**	**Height (cm)**	**Depth* (cm)**	**Depth2 (cm)**	**Volume (m^3)**	**Volume** (m^3)**	**Area (m^2)**	**Area** (m^2)**	**Back width (cm)**
5	0	276,1	90,0	117,0	190,0	128,1	6,1	4,7	5,2	4,1	0,0
	30	253,5	90,0	164,5	174,5	112,5	7,3	5,8	4,4	3,5	0,0
	45	226,7	90,0	176,2	156,0	94,1	6,2	5,1	3,5	2,9	0,0
8	0	177,7	90,0	117,0	190,0	105,9	4,5	3,9	3,8	3,3	9,7
	30	171,5	90,0	164,5	182,5	98,4	5,8	5,1	3,5	3,1	9,7
	45	164,1	90,0	176,2	173,6	89,5	5,7	5,1	3,3	2,9	9,7
12	0	153,1	90,0	117,0	190,0	92,7	4,7	4,1	4,0	3,7	18,6
	30	148,6	90,0	164,5	182,5	85,2	6,2	5,4	3,8	3,5	18,6
	45	130,9	90,0	176,2	173,6	76,3	5,6	4,9	3,2	3,0	18,6
15	0	134,5	90,0	117,0	190,0	83,0	4,6	3,9	4,0	3,7	22,0
	30	131,1	90,0	164,5	182,5	75,5	6,2	5,2	3,8	3,5	22,0
	45	118,3	90,0	176,2	173,6	66,6	5,8	4,8	3,3	3,1	22,0
18	0	122,8	90,0	117,0	190,0	73,3	4,7	3,8	4,0	3,8	24,2
	30	120,0	90,0	164,5	182,5	65,8	6,3	5,1	3,9	3,6	24,2
	45	110,1	90,0	176,2	173,6	56,9	6,1	4,8	3,4	3,2	24,2
20	0	117,1	90,0	117,0	190,0	66,9	4,8	3,8	4,1	3,8	25,3
	30	114,6	90,0	164,5	182,5	59,4	6,5	5,0	3,9	3,7	25,3
	45	106,0	90,0	176,2	173,6	50,5	6,2	4,7	3,5	3,3	25,3
22	0	112,6	90,0	117,0	190,0	60,4	4,9	3,7	4,2	3,9	26,2
	30	110,3	90,0	164,5	182,5	52,9	6,6	5,0	4,0	3,8	26,2
	45	102,7	90,0	176,2	173,6	44,0	6,5	4,7	3,7	3,4	26,2

Table 7 Triangular & three flat vertex configuration comparison

3.3.1 CONSIDERATIONS AND CHOSEN DESIGN

From the results obtained in the model the conclusion that can be drawn are:

- Any triangular configuration needs slightly more space for the same number of modules than a rectangular one. However, the triangular one offers more flexibility in the geometrics of the MOD-Hub as it allows for both linear and circular topologies.
- The flat point model does not save much area of space, but it helps lowering the depth in linear topologies, as in the circular would not make any difference.

- The more slope there is for the bike, the smaller the modules. Although, this would make necessary a stopper system for the bike when in storage.
- For the triangular design a high number of modules in the circular configuration is more suitable as the width reduces up to less than a meter (20~ sides topologies). This parameter alternatively can be reduced using the three flat vertex designs resulting into more reasonable topologies for sharing schemes.

Bearing all of this in mind, the three flat vertexes design was chosen along with a 12 hubs configuration. It provides with a reasonable number of bike parking space for circular configurations, as has been seen in most existing systems, as well as offering a good compromise between sizes.

A 3D model was created using Solid Edge ST4 software, which also enabled to visualize the result of both a circular and a linear set up.

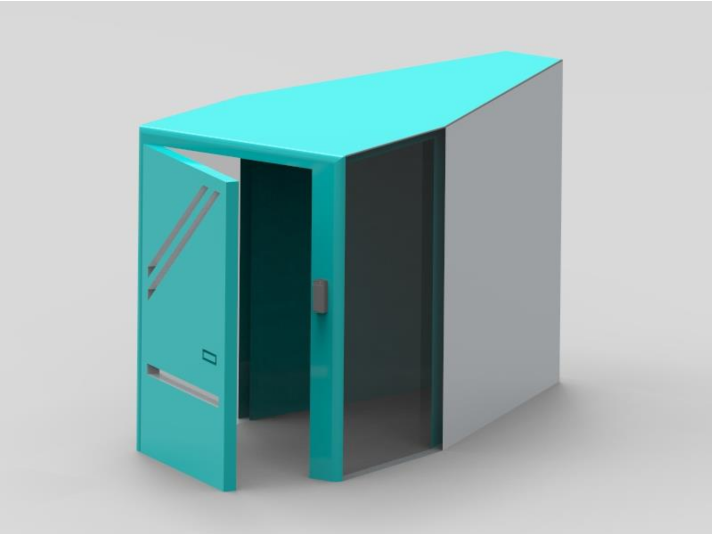


Figure 34 MOD-Hub 3D model of the locker

The final dimensions and design summary can be seen in Section 0

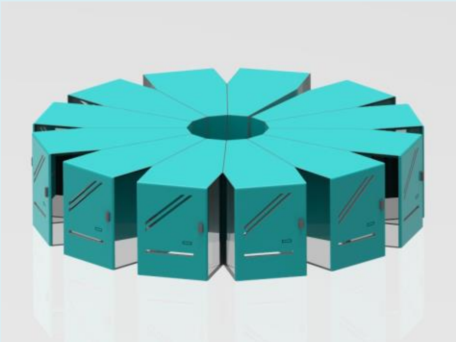
Circular configuration		Diameter = 5,14 m
Linear configuration		Total length = 2,8 m

Table 8 Dimensions 12-sides topology for different configurations

3.4 BIKE STORAGE DESIGN

Every locker will require a bike stopping and stabilization system. This will facilitate and make safe the introduction and the extraction of the bike from the module. The complexity of this system will depend on the selected locker and if the bike will be storage horizontally or inclined.

3.4.1 HORIZONTAL LOCKING

This type of locker represents the simplest configuration. It would only need a rail and a wheel supporting structure as the one shown below. However, in our case the rail must be fixed to the module. This system will keep the bike steady and easy to push in or pull out with minimum effort.

Figure 35 Horizontal bike rail

3.4.2 SEMI-VERTICAL LOCKER

On one hand, a locker in which the bike is stored inclined allows to save space in the street, but on the other hand, it requires for a more complex retention and release system.

First, as it is a system that it is aimed for all kind of people we must look at how much force would be necessary to lift the bike in the different configurations.

3.4.2.1 Force needed to lift the bike

The main force that the user will have to deal with is the weight of the bicycle. We will consider a generic e-bike weight of 25kg. The friction force does not affect the bicycle as the wheels rotate and there only exist friction in the wheel bearings which can be negligible. This will result in the user having to push with the force F_{user}.

$$F_{user} = W_x = W \cdot \sin\alpha$$

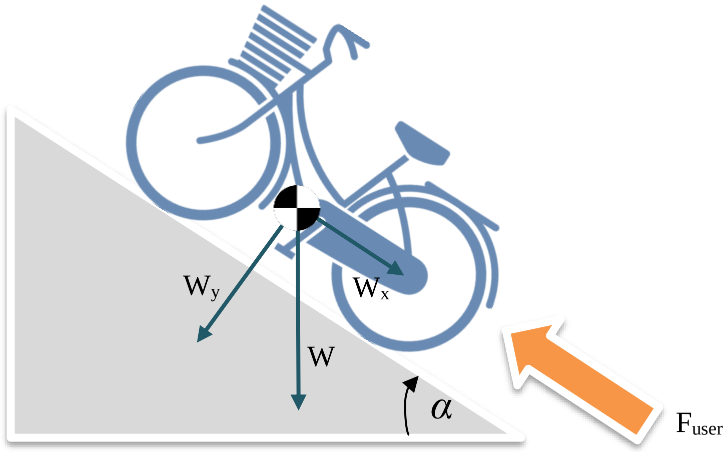


Figure 36 Forces affecting the bike

For the main configurations of the inclination proposed, the results of the equivalent weight to be moved are:

Angle (°)	F_{user} (kg)
0	0
15	6,5
20	8,6
30	12,5
45	17,7

Table 9 Equivalent weight to be moved by the users

3.4.2.2 Stopping systems

Bearing in mind the force calculated, the next step is to evaluate which systems currently exist and can be implemented in our solution. In order to achieve this, there are a number of possibilities.

3.4.2.2.1 Fixed hooks

The simplest solution would be to fix a hook at the back of the locker so that users can hook up the bike. This is an easy installation system but would require making the floor in a way that allow certain mobility of the wheel sideways to be able to put the wheel in the hook. Perhaps a rail wide enough could be used to permit that certain slack and at the same time serve as a guide the bike and keep it straight. This kind of hooks are designed for storing bikes completely vertical, so they should be strong enough to hold a bike semi-vertically.

Figure 37 Wheel hook retention system

A variation of this possibility is a hook which holds the bike from the handlebar. Bear in mind that the installation position could differ from the schematic below as it could be adapted to our needs.

Figure 38 Handlebar hook retaining system

The disadvantage of these systems is that the user will not have an easy access to the front of the bike when it is stored inside the locker because as the low ceiling.

3.4.2.2.2 Semi vertical racks

An alternative solution is the use of vertical racks similar to the ones for the horizontal locker but in a shape which will allow the bike to retain itself inclined. There are two different approaches to this idea. First, a rack with a curvature for the rear wheel which holds the bike from the back and second, a rack with a gap for the front wheel at the top of the structure which holds the bike from the front.

3.4.2.2.2.1 Semi-vertical rack for the rear wheel

In this case, the bike is supported from the back with a curvature in the structure and can be released in a safe way by pulling from the back. The downside of this alternative is that to store the bike in the rack it has to overcome the small step originated from the shape of the structure. This could be sorted with a foldable mini-ramp which once the bike is in position would stay inside the module.

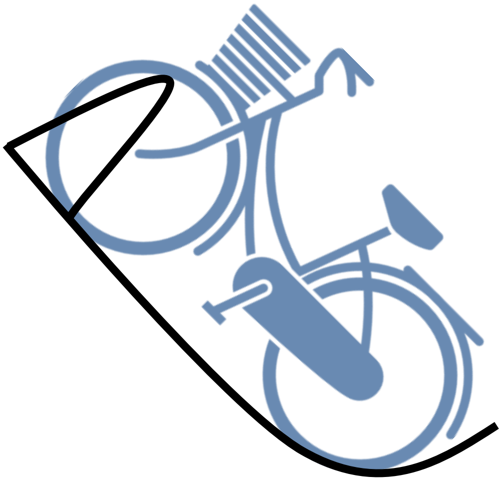


Figure 39 Semi-vertical rack retention system rear wheel

3.4.2.2.2.2 Semi-vertical rack for the front wheel

This other approach gets to the same solution but in our case, as the bike will be accessible through the saddle and the rear it is more inconvenient to release the bike from the rack than in the rear wheel option.

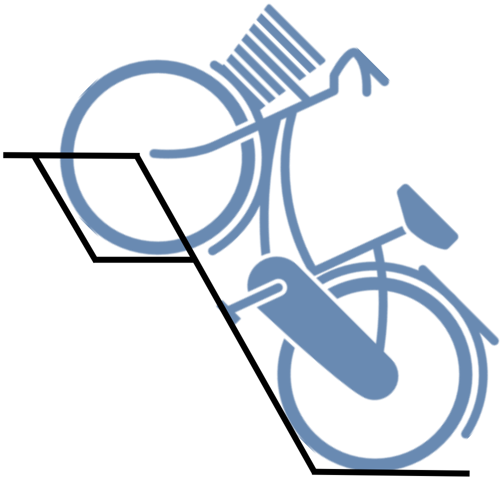


Figure 40 Semi-vertical rack retention system front wheel

3.4.2.2.2.3 Manual elevator with pulleys

An alternative is the development of a manual pulley system to lift the bikes. Thanks to the pulleys, the effort to lift the bike would be minimum. The bike could be griped by means of a hook, a clench or any detachable mechanism. In any case, having moving parts implies more maintenance and supervision.

Furthermore, the elevator could be operated by a motor and thus, automated, but this would increase the price and complexity of the whole system.

Figure 41 Manual elevation system

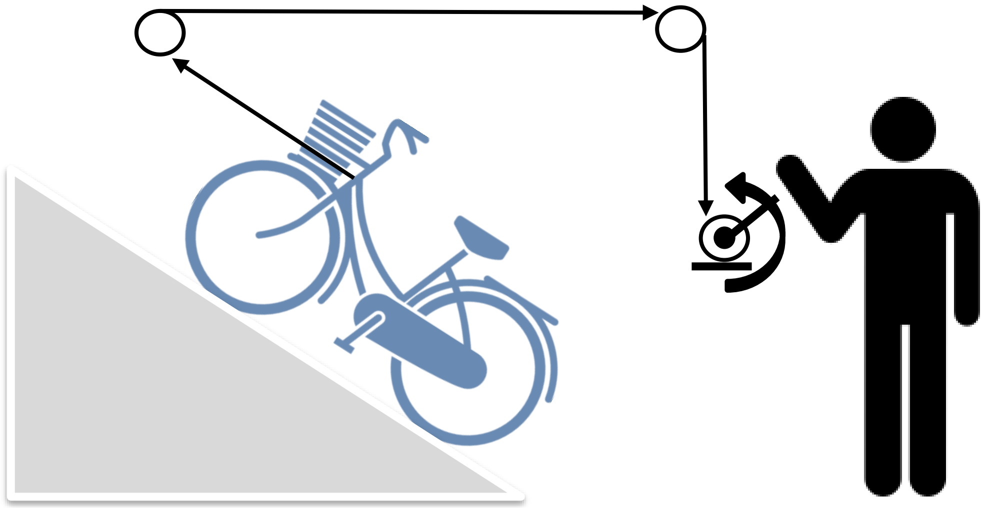


Figure 42 Manual elevator operation

3.4.3 CONSIDERATIONS AND CHOSEN ALTERNATIVE

The horizontal locker has an easy support system solution while the semi-vertical storages offer a wider variety of solutions each one with their pros and cons. The following conclusions can be extracted from the analysis:

- A fixed hook for the handlebar or the wheel are the simplest systems, however they require certain slack for the bike to be engaged and can be inconvenient to use because only the rear of the bike is accessible.
- The semi-vertical racks are a fixed mechanical solution with little complexity, but they might require an extra effort from the user to store the bikes.
- A pulley system would guarantee an easy and smooth operation, but it requires more maintenance and supervision as mechanisms and moving parts are always more demanding in that matter.

As a flat locker was chosen, only a rail with the wheel securing bars would be necessary. Eventually, as the lockers are made for the bikes to fit perfectly, the bike could be kept vertically by leaning on the locker wall. However, this could result in more worn out of the interior, and the bikes would be less easy to retrieve.

3.5 MODULE CONNECTION DESIGN

A basic aspect of any modular design is how are the different modules going to be connected and fixed together and act as a unit. In our case not only is a modular design but we want it to support two configurations: circular and linear.

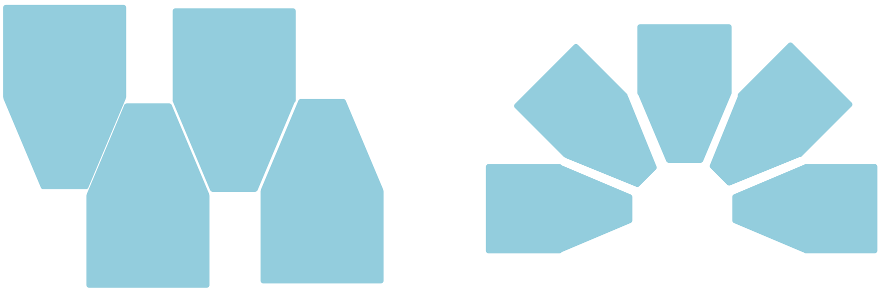


Figure 43 e-Hub different configurations

This means that the connection between lockers must be compatible with both geometries and the only way to achieve this using only one connection point is having it centred and on both sides.

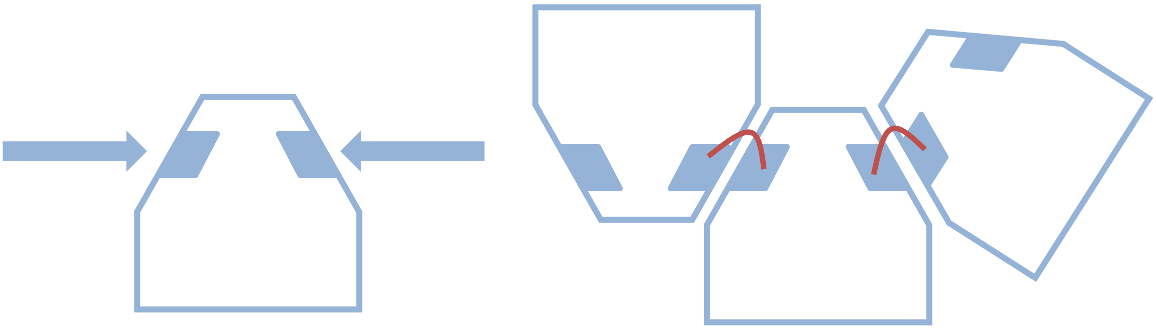


Figure 44 Module connection location

These links could consist of panels with screws which in the case of joining modules would be unscrewed. Then the link cables would be introduced through the gap left by the panel and connected to their specific connectors inside the module.

3.6 CONNECTORS AND ELECTRIC ENCLOSURES REQUIREMENTS

In order to comply with electrotechnics normative, the enclosures of the electrical equipment and electrical canalizations (plugs, connectors, cables and enclosures) must have a minimum protection against external conditions. This is referred using the IP and the IK codes.

IPXX is an international standard referred to the CEI *60529: Degrees of Protection* [26] which stablishes the requirements and the classification of the degrees of protection of electrical canalizations and equipment enclosures from external hazards.

IK rating refers to the European standard EN 62262 — the equivalent of international standard IEC 62262 (2002) [27]. It is an international numeric classification for the degrees of protection provided by enclosures for electrical equipment against external mechanical impacts.

For an installation of infrastructure for charging electric vehicles, the Spanish regulation (ICT-BT-52) determines that the minimum protection in these cases are the ones showed in **¡Error! No se encuentra el origen de la referencia.**. The values showed are the ones for electric vehicles charging points in the exterior, the most adverse scenario, but as in our case they would be placed inside the lockers there might be applicable softer codes.

	Solids	Liquids	Mechanical Impacts
Cables canalizations	IP4X or IPXXD	IPX4	-
Equipment enclosures	IP5X	IPX4	IK08

Table 10 IP and IK minimum standards [28]

Code	Effective against
IP4X	Solids >1mm
IP5X	Dust protection
IP4X	Splashing of water from any direction
IK08	Impacts <= 5 Joules

Table 11 Meaning applicable IP and IK standards [29] [30]

The minimum requirements for our electrical canalizations will be then IP44 and for the electric enclosures IP54 and IK08.

3.7 OTHER CONSTRUCTIVE REQUIREMENTS

Furthermore, power supply cables must have more than 2,5 mm diameter if they are made of copper or 4mm if aluminium. Copper will be preferred as it has no degradation derived from galvanic corrosion.

Also, the normative establishes there must be 20 lux luminance at floor level for exterior charging points, so some source of light will have to be installed in the modules for night operation.

As the e-Hub is intended for more than 5 charging points, the addition of harmonic protection filters to avoid harmonic distortion and the issues they cause should be studied in detail. However, it is not mandatory and the power required for each module is minimum.

The automatic switches for electrical protection are designed as in any other installation: considering the maximum current that the system will consume and selecting the appropriate calibre and required protection curve outline.

3.8 FINAL DESIGN

To sum up, the final design chose for the hubs is the last variation of the triangular design with a 0º inclination and a 12-module circular configuration.

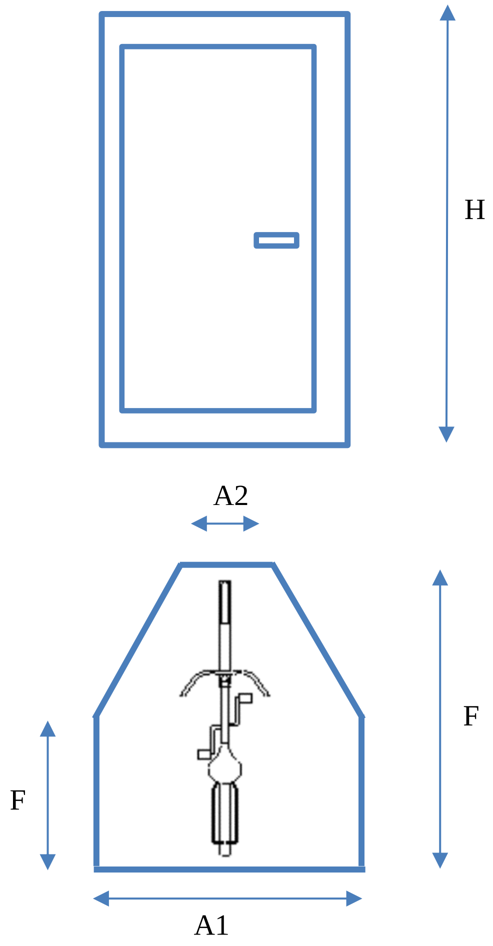


Figure 45 Final shape for the MOD-Hub

H (cm)	**120**
F1 (cm)	**190**
A1 (cm)	**90**
F2 (cm)	**67**
A2 (cm)	**25.3**

Table 12 Final dimensions of the MOD-Hub

	Solids	Liquids	Mechanical Impacts
Cables canalizations	IP4X or IPXXD	IPX4	-
Equipment enclosures	IP5X	IPX4	IK08

Table 13 IP and IK enclosures requirements

In the inside of the locker there will be a bike rail with a structure to keep the bike in a vertical position, like the one in Figure 35.

CHAPTER 4. CONTROL SYSTEM

In this chapter the control system is described in detail: its general design, its distinct parts a and the programs functioning flow. The main task of the Control Systema is to control each one of the individual modules. To achieve this, a control board has been developed. Each one of the modules will require one control board to work.

During this time, two versions of the control board were developed: a V0.1 to serve as proof of concept and test the different circuits; and a V1.0 with corrections made from V0.1. Additionally, the libraries and drivers that have been developed for each one of the functions will be explained. The schematics of version 1.0 can be consulted in **¡Error! No se encuentra el origen de la referencia.**.

4.1 GENERAL STRUCTURE OF THE CONTROL SYSTEM

As an overview, the control board is in charge of processing the inputs of every module, and then responding to them accordingly. This requires reading measures form sensors, messages form an RFID reader and from the communications module. Then, the board actuates on relays, LEDs or sends messages to the communications board. To achieve these goals, the board counts with a microcontroller unit (MCU) that has been selected and programmed accordingly.

The functional block diagram of the control board is as follows:

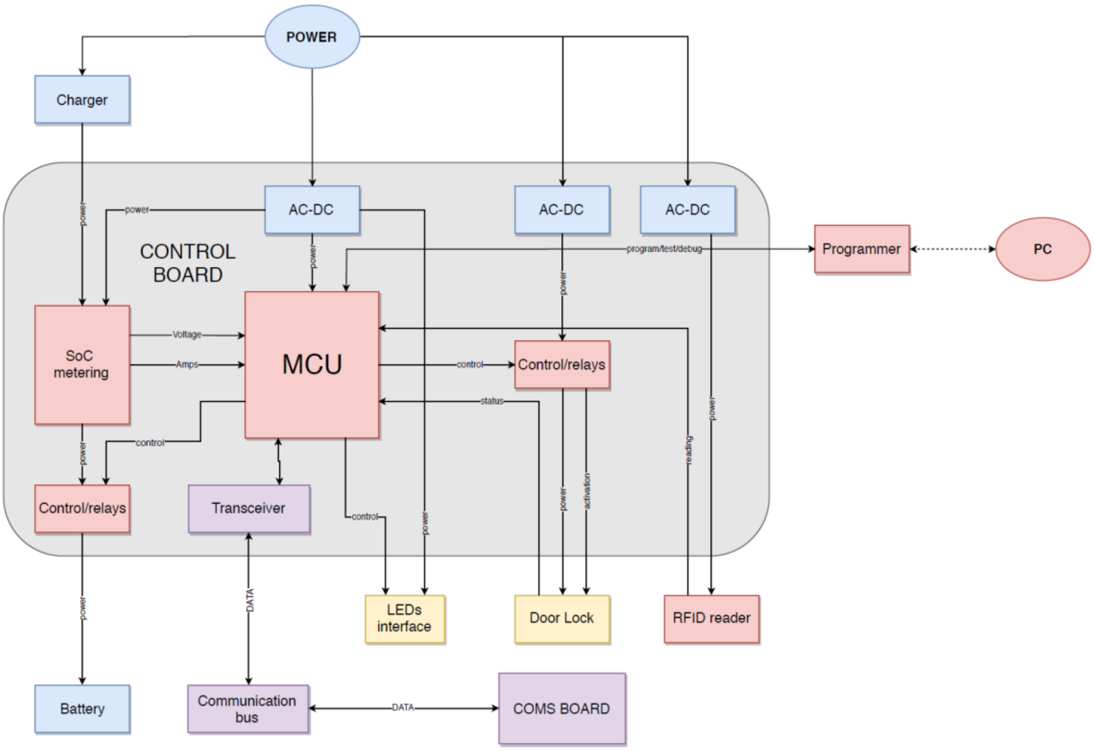


Figure 46 Control board block diagram

In Figure 46, in blue there are the elements related with power supply, in purple the elements related with communications and in red, the elements related with control; the rest are generic actuators. As it is shown then, the control board oversees:

- Battery state of charge (SoC) measuring and Flow control.
- RFID tag reading.
- Door opening and status monitoring.

4.1.1 POWER SUPPLY

The elements and components used were the ones that determined the voltages and power supplies required. The RFID reader works at 5V, the door electric mechanism work at 12V and the microcontroller unit and communication bus work at 3.3V, so accordingly three different AC/DC converters have been included. All of them work from the input of a monophasic line of 230V. To ensure the voltage stability, it is a good practice to include

470µF capacitors. Additionally, to visually see if the power supply is working and as a self-tester, a LED diode was included.

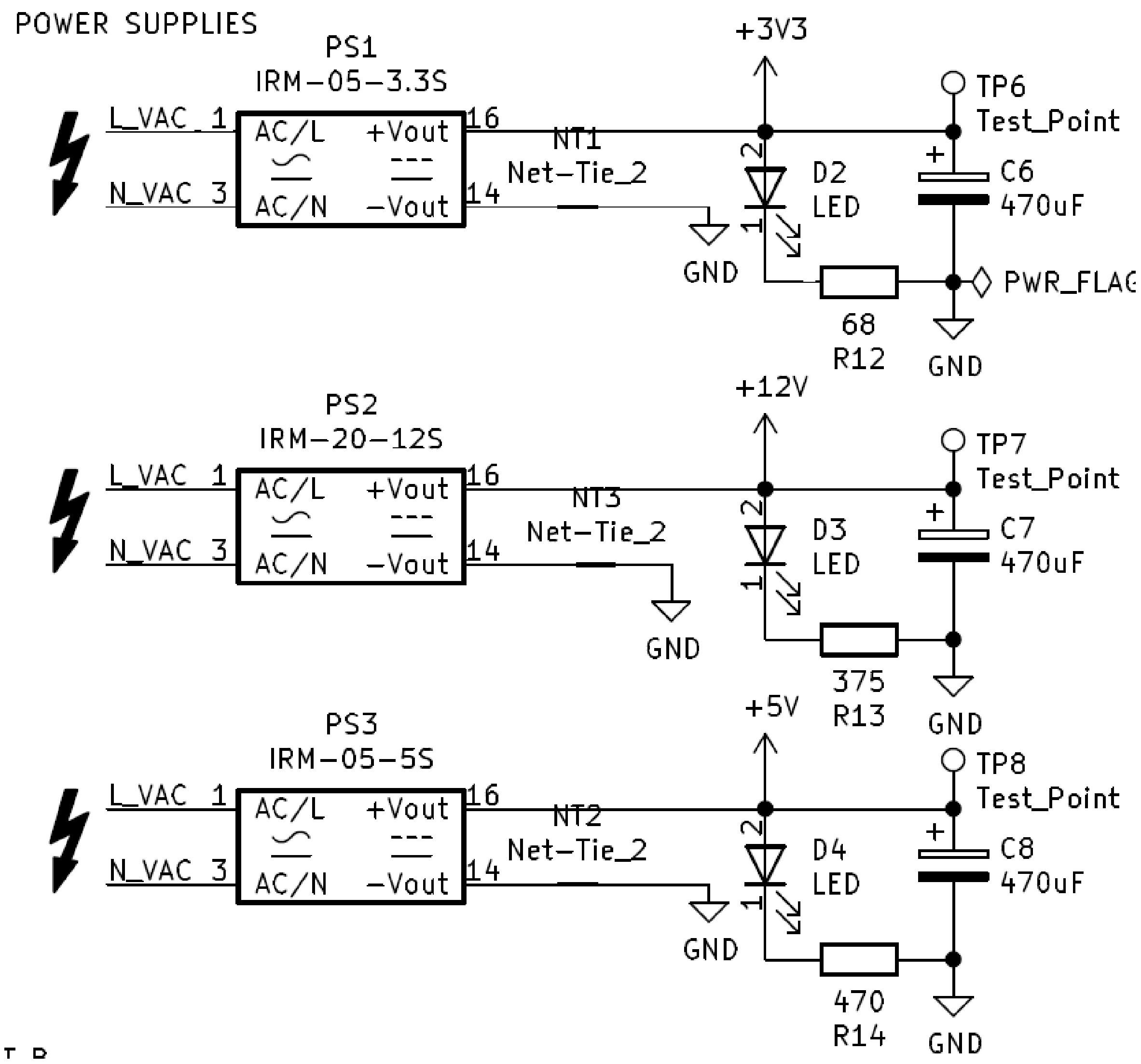


Figure 47 Power supply circuits for control system

The AC/DC converters used were form the US manufacturer MeanWell because of their price range and many models for different power requirements.

For the door electric mechanism, it was assumed that the circuit would consume up to 1A, so a minimum of 12W would be needed. As initially, the RFID reader was also going to use the same power source, the 20W converter model was selected. For the 5V supply, only the

RFID reader was going to use the power source so the 5W model has been selected. Last, for the 3.3V power source, it was estimated that the total consumption would be less than 5W, so it was selected the corresponding model.

Voltage	**3.3V**	**5V**	**12V**
Application	MCU, control of relays, SoC metering circuits, communications circuits	RFID reader	Electric door mechanism
Estimated consumption	4W	4W	18W
Selected model	IRM-05-3.3	IRM-05-5	IRM-20-12

Table 14 Power supply estimations for the control system

4.2 MICROCONTROLLER

For the selection of the microcontroller first an analysis of the required pins, the peripherals needed, and the computing requirements was made. Then, due to previous experience with Microchip microcontroller, the most suitable model from the existing devices families was selected.

First of all, the estimations of the needed peripherals:

- Operating voltage: 3.3V
- At least 3 timers
- Analog to Digital Converters (ADCs) for at least 2 different measures
- At least 2 Universal Asynchronous Receiver-Transmitters (UARTs)
- At least 256kB of program flash memory
- Low power consumption
- Enough computing power to deal with high level communications

A 32-bit microcontroller was chosen in order to be able to handle high level communications protocols and to be able to work with float numbers. Bearing this in mind, the most suitable family devices was the PIC32MX1, which offer the required peripherals at a lower cost and have a 72 MHz/116 DMIPS MIPS32 M4K core with more than enough computing power. The specific model selected is the PIC32MX174F256B, which counts with the following peripherals and pins.

Core freq. (MHz)	Pins	Program Memory (kB)	Timers	UARTs	ADC channels	I/O pins
72	28	256+12	5	2	10	21

Table 15 PIC32MX175F256B peripherals [26]

The selected MCU counts with 28 pins with the functions of each one described in Table 16.

Pin #	Full Pin Name	Pin #	Full Pin Name
1	MCLR	15	PGEC3/RPB6/ASCL2/PMD6/RB6
2	VREF+/AN0/C3INC/RPA0/ASDA1/CTED1/PMA1/RA0	16	TDI/RPB7/CTED3/PMD5/INT0/RB7
3	VREF-/AN1/RPA1/ASCL1/CTED2/RA1	17	TCK/RPB8/SCL1/CTED10/PMD4/RB8
4	PGED2/AN2/C1IND/C2INB/C3IND/RPB0/RB0	18	TDO/RPB9/SDA1/CTED4/PMD3/RB9
5	PGEC2/AN3/C1INC/C2INA/LVDIN/RPB1/CTED12//RB1	19	V_{SS}
6	AN4/C1INB/C2IND/RPB2/SDA2/CTED13/RB2	20	VCAP
7	AN5/C1INA/C2INC/RTCC/RPB3/SCL2/RB3	21	PGED1/RPB10/CTED11/PMD2/RB10
8	V_{SS}	22	PGEC1/TMS/RPB11/PMD1/RB11
9	OSC1/CLKI/RPA2/RA2	23	AN12/PMD0/RB12
10	OSC2/CLKO/RPA3/PMA0/RA3	24	AN11/RPB13/CTPLS/PMRD/RB13
11	SOSCI/RPB4/RB4	25	CVREFOUT/AN10/C3INB/RPB14/SCK1/CTED5/PMWR/RB14
12	SOSCO/RPA4/T1CK/CTED9/RA4	26	AN9/C3INA/RPB15/SCK2/CTED6/PMCS1/RB15
13	V_{DD}	27	AV_{SS}
14	PGED3/RPB5/ASDA2/PMD7/RB5	28	AV_{DD}

Table 16 PIC32MX174F256 Pin Names [31]

The pins that be needed to control the different components and the required function of the pin in the MCU are shown in Table 17. The programming of the MCU is done through PGED1/PGEC1 with the In-Circuit Serial Programming (ICSP) interface and with a Microchip PICKIT3 programmer.

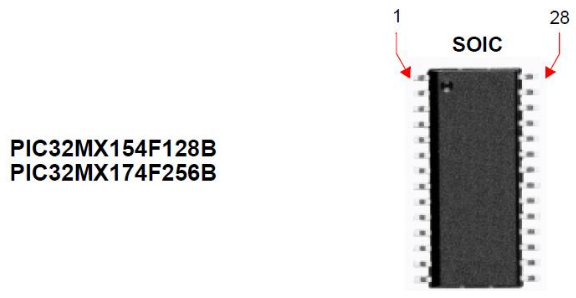


Figure 48 PIC32MX174F256B with SOIC-28 package [31]

PIN number	Function	I/O	PORT	FUNC TYPE	PIN TYPE
1	MCLR	I/O	-	RESET	RESET
2	TX_COM	O	RA0	U1TX	RPA0
3	RFID_RX_LV	I	RA1	U2RX	RPA1
4	V_OUT_VOLTAGE	I	RB0	AN2	ANALOG
5	V_OUT_CURR	I	RB1	AN3	ANALOG
6	DIR_COM	O	RB2	RB2	DIO
7	RFID_DO_LV	I	RB3	RB3	DIO
8	VSS	-	-	POWER	POWER
9	RX_COM	O	RA2	U1RX	RPA2
10	RFID_TX_LV	O	RA3	U2TX	RPA3
11	RFID_D1_LV	I	RB4	RB4	DIO
12	ALIM_ACT	I/O	RA4	RA4	DIO
13	VDD	-	-	POWER	POWER
14	DOOR_ACT	O	RB5	RB5	DIO
15	DOOR_SENSOR_LV	I	RB6	RB6	DIO
16	SW01	I	RB7	RB7	DIO
17	STANDBY_CURR	O	RB8	RB8	DIO
18	OVERCURR_CURR	I	RB9	RB9	DIO
19	VSS	-	-	POWER	POWER
20	VCAP	-	-	POWER	POWER
21	PGED1	I/O	RB10	PGED1	ICSP
22	PGEC1	I/O	RB11	PGEC1	ICSP
23	RFID_LED_LV	O	RB12	RB12	DIO
24	LED_1	O	RB13	RB13	DIO
25	LED_2	O	RB14	RB14	DIO
26	LED_3	O	RB15	RB15	DIO
27	AVSS	-	-	POWER	POWER
28	AVDD	-	-	POWER	POWER

Table 17 Pin list of MCU in the control board

As the oscillator of the MCU, the internal Fast RC oscillator of 8MHz, which is processed by the systems PLL to achieve a System Clock (SYSCLK) of 40Mhz, and a Peripheral Bus Clock (PBCLK) of 5MHz. To achieve this, the configuration bits for the MCU are the following (the oscillator configuration code has been highlighted). As this is just the start of the development, features like the watchdog timer, code protection and sleep/idle modes have not been configured.

```
// Configuration bits for PIC32MX174F256B
// Configuration bits: selected in the GUI (MCC)

// DEVCFG3
// USERID = No Setting
#pragma config AI2C1 = OFF              // Alternate I/O Select for I2C1 (I2C1
uses the SDA1/SCL1 pins)
#pragma config AI2C2 = OFF              // Alternate I/O Select for I2C2 (I2C2
uses the SDA2/SCL2 pins)
#pragma config PMDL1WAY = OFF            // Peripheral Module Disable
Configuration (Allow multiple reconfigurations)
#pragma config IOL1WAY = OFF             // Peripheral Pin Select Configuration
(Allow multiple reconfigurations)

// DEVCFG2
#pragma config FPLLIDIV = DIV_2         // PLL Input Divider (2x Divider)
#pragma config FPLLMUL = MUL_20         // PLL Multiplier (20x Multiplier)
#pragma config FPLLICLK = PLL_FRC       // (FRC is input to the System PLL)
#pragma config FPLLODIV = DIV_2         // System PLL Output Clock Divider (PLL
Divide by 2)

#pragma config BOREN = ON               // Brown-Out Reset (BOR) Enable (Enable
BOR)
#pragma config DSBOREN = OFF            // Deep Sleep BOR Enable (Disable ZPBOR
during Deep Sleep Mode)
#pragma config DSWDTPS = DSPS32         // Deep Sleep Watchdog Timer Postscaler
(1:2^36)
#pragma config DSWDTOSC = LPRC          // Deep Sleep WDT Reference Clock
Selection (Select LPRC as DSWDT Reference clock)
#pragma config DSWDTEN = ON             // Deep Sleep Watchdog Timer Enable
(Enable DSWDT during Deep Sleep Mode)
#pragma config FDSEN = OFF              // Deep Sleep Enable (Disable DSEN bit in
DSCON)

// DEVCFG1
#pragma config FNOSC = 0x1              // Oscillator Selection Bits
(FRCDIV+System PLL)
#pragma config FSOSCEN = OFF            // Secondary Oscillator Enable (Disabled)
#pragma config IESO = OFF               // Internal/External Switch Over
(Disabled)
```

```
#pragma config POSCMOD = OFF              // Primary Oscillator Configuration
(Primary osc disabled)
#pragma config OSCIOFNC = OFF             // CLKO Output Signal Active on the OSCO
Pin (Disabled)
#pragma config FPBDIV = DIV_8             // Peripheral Clock Divisor (Pb_Clk is
Sys_Clk/8)

#pragma config FCKSM = CSECME             // Clock Switching and Monitor Selection
(Clock Switch Enable, FSCM Enabled)
#pragma config WDTPS = PS1048576          // Watchdog Timer Postscaler (1:1048576)
#pragma config WDTSPGM = ON               // Watchdog Timer Stop During Flash
Programming (Watchdog Timer stops during Flash programming)
#pragma config WINDIS = OFF               // Watchdog Timer Window Enable (Watchdog
Timer is in Non-Window Mode)
#pragma config FWDTEN = OFF                // Watchdog Timer Enable (WDT Enabled)
#pragma config FWDTWINSZ = WINSZ_25       // Watchdog Timer Window Size (Window
Size is 25%)

// DEVCFG0
#pragma config JTAGEN = OFF               // JTAG Enable (JTAG Disabled)
#pragma config ICESEL = ICS_PGx1          // ICE/ICD Comm Channel Select
(Communicate on PGEC1/PGED1)
#pragma config PWP = OFF                  // Program Flash Write Protect (Disable)
#pragma config SMCLR = MCLR_NORM          // Soft Master Clear Enable (MCLR pin
generates a normal system Reset)
#pragma config BWP = OFF                  // Boot Flash Write Protect bit
(Protection Disabled)
#pragma config CP = OFF                   // Code Protect (Protection Disabled)
```

Finally, for the elements added to the MCU to have stable power supplies, reset switch and programming according to the manufacturers recommendations are as shown in Figure 49. For isolating areas of the board to debug and track down errors a jumper was added in the power supply.

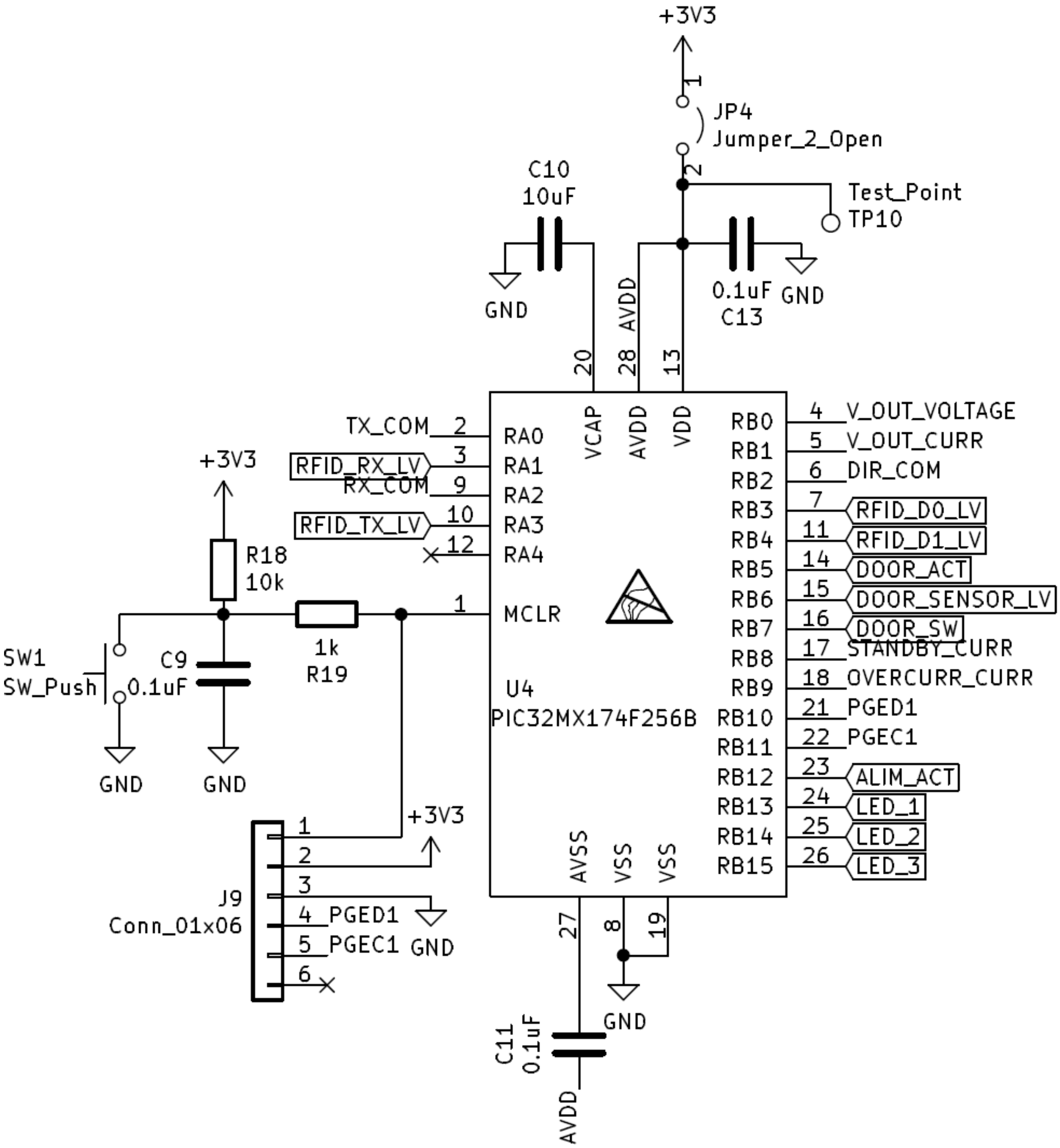


Figure 49 PIC32MX174F256B schematic in the control board

4.2.1 TESTING LEDS AND SWITCHES

In order to easily carry tests with the hardware and simulate inputs and outputs, there were added to the circuit a number of LEDs and a switch.

The LEDs are activated trough a bipolar junction transistor (BJT) with a NPN structure: BC237 N-BJT transistor. This way, the consumption of the MCU can be limited and the risk of overheat and saturation of the MCU pins is reduced.

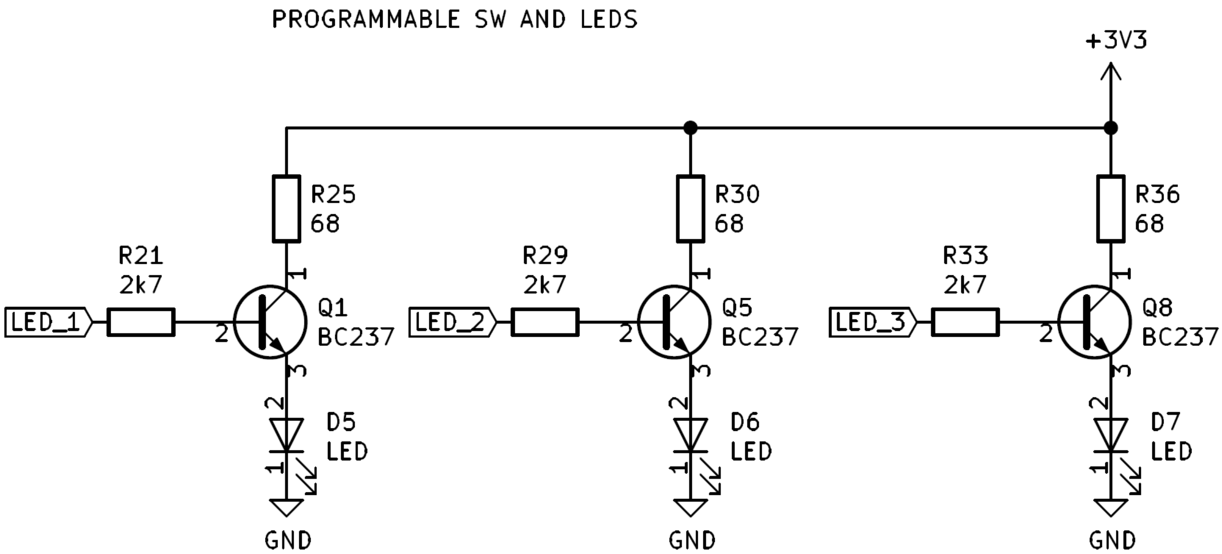


Figure 50 Test LEDs circuit

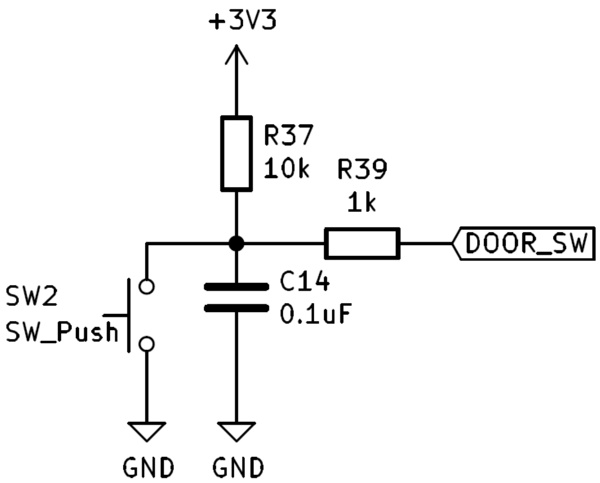


Figure 51 Test switch circuit

The LEDs are 2.1 V diodes with a nominal current of 20mA. The transistors are used as switches, so they will work in the saturation mode and the have a voltage drop between the base and the emitter of 0.7 V. For the MCU to supply 0.2 mA the required resistor is $R_b = 3\ k\Omega$ and the resistor at the collector of the transistor must be of $R_c = 68\ \Omega$. Using common commercial resistors with a 5% tolerance that have price and high availability, the values used are $R_b = 2.7\ k\Omega$ and $R_c = 68\ \Omega$ which will make the diodes to light brighter but will not cause any harm to the circuit. For the switch, the same circuit given by the manufacturer for the reset switch is used but it will have to bear in mind that is a low level active switch. The design of the BJT transistor circuit for the LEDs is as follows:

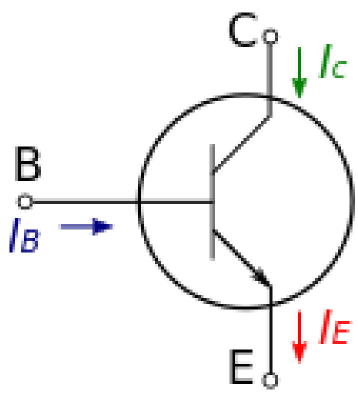


Figure 52 BJT NPN transistor diagram [32]

$$I_E = I_B + I_C$$

$$I_C = \beta \cdot I_B$$

$$I_B = 0.2\ mA$$

$$I_E = 20\ mA$$

$$\beta = 100$$

$$V_B - V_E = 0.7\ V$$

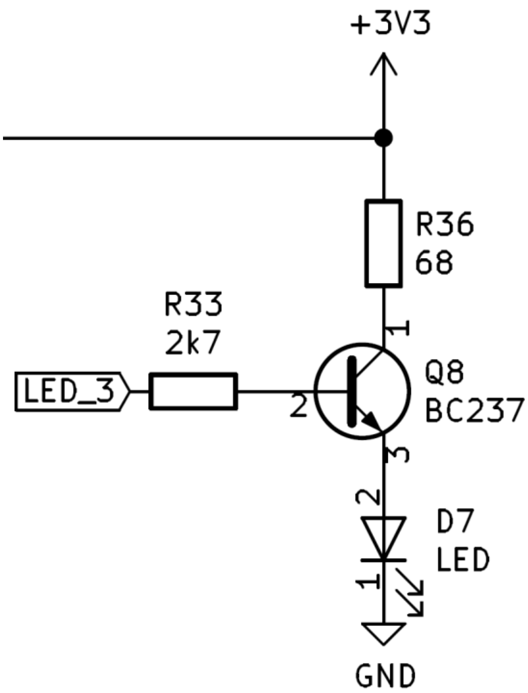


Figure 53 Circuit test LEDs in detail

$$V_{D7} = 2\ V$$

$$V_{LED\_3} - I_B \cdot R_{33} - V_{BE} = V_{D7}$$

$$R_{33} = 3\ k\Omega$$

$$R_{36} = \frac{V_{+} - V_{D7}}{I_C} = 65\ \Omega$$

4.3 BATTERY CONTROL

One of the main tasks of the control board is to measure the battery status of the ebikes. To achieve this, the board must be able to take measures of different parameters of the battery and then estimate the State of Charge (SoC).

The main measures to be taken are the voltage of the battery and the current that is being supplied. Thanks to these two figures and a characteristic curve of the battery's type technology, in our case Lithium Polymer (LiPo), we can estimate within a range of accuracy the actual status of the battery. Normally in similar commercial applications voltage is enough as they usually give an estimation with four levels of battery from 1 to 4 with a LED display. In our case, we will be able to give a more precise estimation thanks to the measuring of the current.

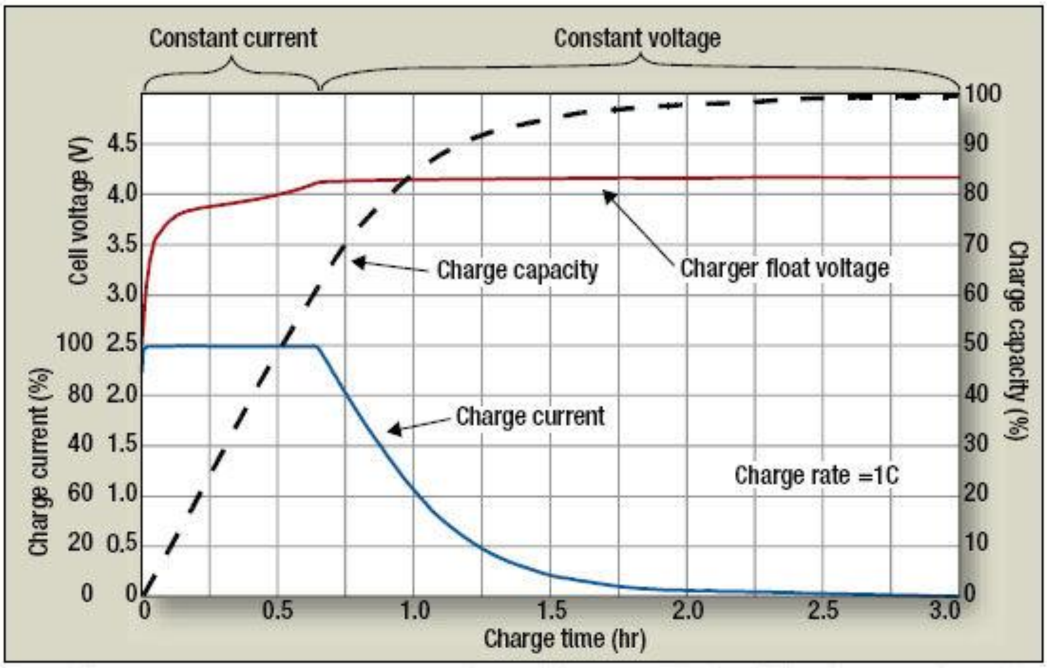


Figure 54 State of charge, voltage and current of a Li-Ion battery cell [33]

In Figure 54 we can see that for Li-Ion batteries the charging cycle starts with a constant current and firstly exponential and then linear increasing voltage region, then a constant voltage and decreasing current region. This means that applications that rely only on voltage measuring consider the batteries charged with approximately 80% of the real charge capacity. For all of this, a current measurement has been included. The parameters of the charger and the battery are included in Table 18.

Battery	Nominal voltage	36 V
	Capacity	11 Ah
Charger	Charger float voltage	42 V
	Charger max power	84 W
	Charger max current	2 A

Table 18 eBike battery and charger parameters

The measures are taken by the MCU's 10-bit Analog to Digital Converter peripheral (ADC), which takes analogic signals and converts them into a number from 0-1024. The PIC32MX174F256B counts with over 10 ADC channels from which we will only use two: one for the voltage measure and another for the current measure. This peripheral will work in a semiautomatic way [34] with interruptions controlled by a timer which will enable them periodically every 5 seconds. When the ADC is enabled the ADC will take 5 measures of each one of the channels and then provide the value of the average of those five measures to reduce the effect of noise. The ADC takes measures from 0V to 3.3V, so the measuring circuits will include the signal adaptation.

This task is controlled by a module of the code which has the following functions.

```
void initBatteryControl(void);
void batteryControl(void);
```

The *intiBatteryControl* function initialises all the inputs and outputs (I/Os), the ADC peripheral (interruptions and configuration) and the corresponding timer. Then in the while loop of the *main* function, the function *batteryControl* is in charge of calculating the SoC from the taken measures periodically and sending them to the communications board.

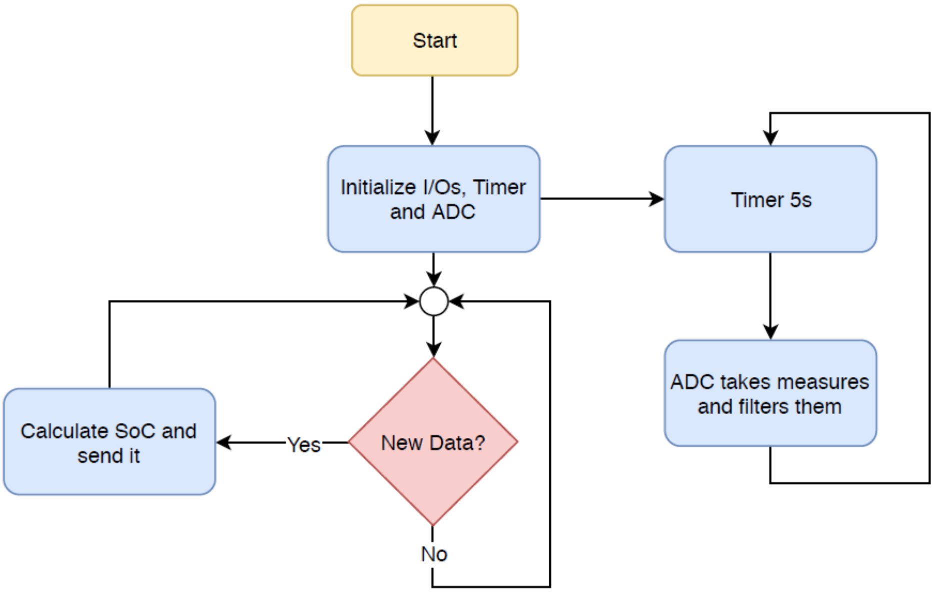


Figure 55 Battery measuring module program flow

4.3.1 VOLTAGE MEASURING

To measure the voltage of the battery a simple circuit with a resistor divisor is used. To reduce distortion of the current measure as a cause of current consumption of the measuring big resistors values have been used. The circuit is basically a signal adaptation in order to get 2.5V in the ADC when the voltage of the battery is at the float level, 42V in our case. Additionally, a filter has been added to make the measurement more stable and noise immune. For the resistive divider of the voltage:

$$V_{out} = V_{in} \frac{R_{17}}{(R_{15} + R_{16} + R_{17})}$$

$$R_{15} = R_{16}$$

$$R_{15} + R_{16} = R_A$$

$$2.5\,V = 42\,V \cdot \frac{R_{17}}{(R_A + R_{17})}$$

$$8.6 \cdot R_{17} = R_A$$

$$R_{15} = R_{16} = 1\,M\Omega$$

$$R_{17} = 150\,k\Omega$$

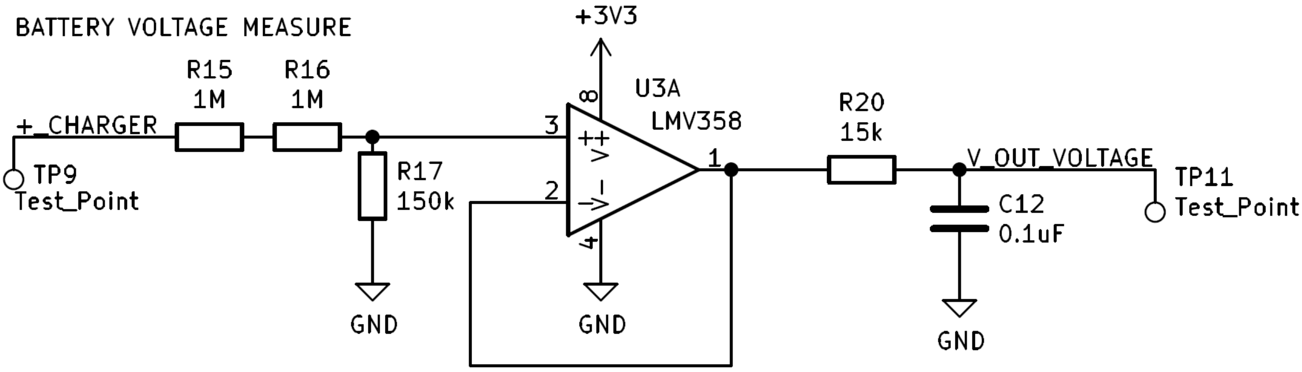


Figure 56 Battery voltage signal adapting circuit

The filter is simply a first order RC filter to absorb noise and small variations. A cut frequency of 100Hz was established.

$$\omega_c = \frac{1}{R_{20} \cdot C_{12}} = 2 \cdot \pi \cdot f$$

$$f = 100\,Hz$$

$$R_{20} \cdot C_{12} = 1.59 \cdot 10^{-3}$$

$$R_{20} = 15\,k\Omega$$

$$C_{12} = 0.1\,\mu F$$

The selected operational amplifier (op. amp.) is a LMV722ID from Texas Instrument, which serves as a general purpose low noise, low voltage amplifier. In the case of this amplifier, in order to calculate the measuring error, the offset voltage, bias and offset current parameters are:

Parameter	Symbol	Value	Total
Offset Voltage	V_{IO}	0.02 mV	$\pm 0.02\ mV$
Offset Current	I_{offset}	260 nA	$260\ \pm 25\ nA$
Bias Current	I_{bias}	25 nA	

Table 19 Bias and offset parameters of op. amp. LMV722ID

$$I_{IO}^{\pm} = I_{offset} \pm I_{bias}$$

$$V_{error} = V_{IO} + V(I_{IO}^{+}) + V(I_{IO}^{-})$$

As the offset have random values within those limits, the maximum function of error is:

$$V_{error} = V_{IO} + I_{IO} \cdot \left(-\frac{(R_A \cdot R_{17})}{(R_A + R_{17})} + R_{20} \right) = 0.038625\ V$$

$$\varepsilon_{abs} = 0.038625\ V$$

$$\varepsilon_{rel\ end\ of\ scale} = \frac{0.038625\ V}{3.3\ V} \cdot 100 = 1.15\% < 5\%$$

4.3.2 CURRENT MEASURING

To measure the current drained into the battery the measuring circuit uses a current transducer. Transducers are devices designed to convert magnitudes into a measurable format, in this case, using magnetic properties we convert current into voltage. For this purpose, as the charger can supply up to 2 Amps, the selected transducer for DC current can measure up to 8 Amps and can be scaled to measure up to 2.67 Amps. The transducer selected is the LEM-HO-8-NP-SP33 which is powered by a 3.3V voltage supply and measures the current that goes through it in both ways. This means that with 0 Amps the transducer delivers 1.65 V, with +2.67 Amps delivers 3.3V and with -2.67 A delivers 0V.

As the current flow is just going to go one way, and the range is of 3.3V, the signal offset must be eliminated, and the signal can be doubled. For this purpose, a voltage subtractor is used, then a buffer is placed between the subtractor and a filter like the one used for the voltage measuring to avoid any interferences between resistors. For the subtracting of the offset the 1.65V voltage reference pin of the LEM is used, granting a precise value.

Figure 57 LEM-HO-8-NP-SP33 current transducer

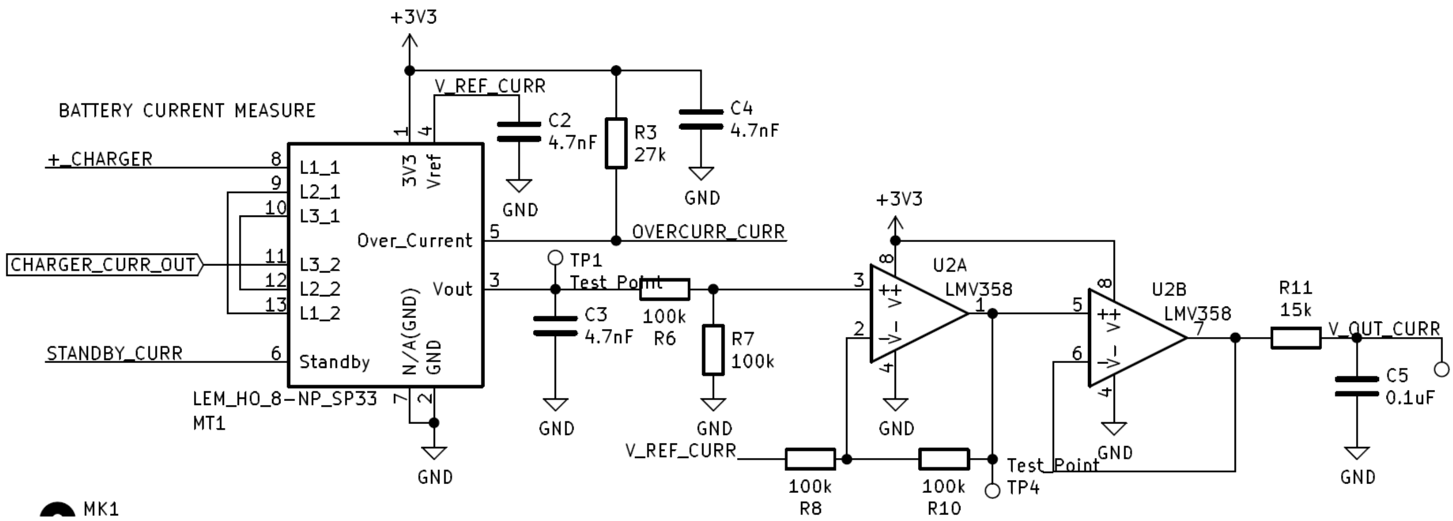


Figure 58 Battery current signal adapting circuit

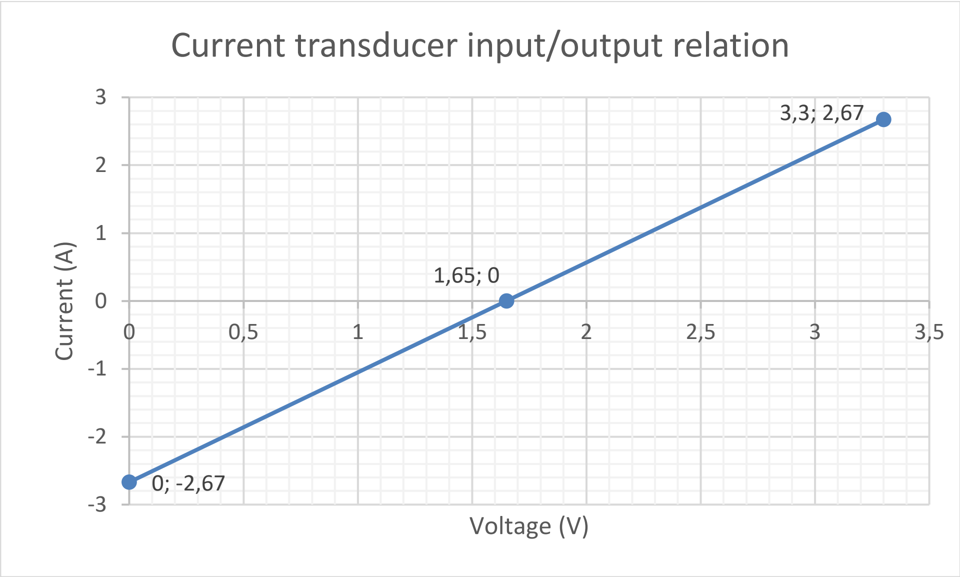


Figure 59 Current transducer output plot

Accrodingly, we want to have 3.3V at the ADC input when the current is maximum (2.67A) and 0 V when it is 0 A. The used circuit is a subtractor inverter with an operational amplifier and after a buffer to ensure isolation.

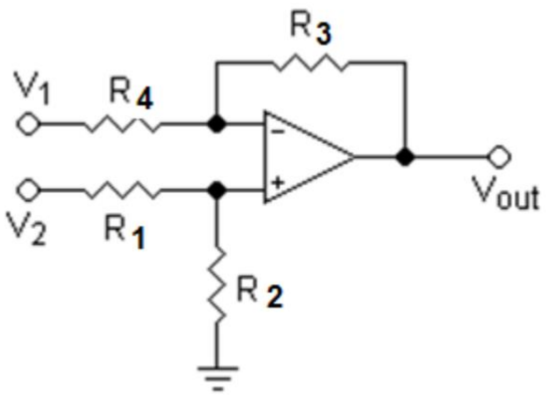


Figure 60 Subtractor operation amplifier circuit

$$V_{out} = V_2 \cdot \frac{R_2}{(R_1 + R_2)} \cdot \left(1 + \frac{R_3}{R_4}\right) - V_1 \cdot \left(\frac{R_3}{R_4}\right)$$

$$V_1 = 1.65\ V$$

$$V_2 = V_{out-LEM}$$

$$R_1 = R_2 = R_3 = R_4 = 100\ k\Omega$$

$$V_{out} = 2 \cdot V_{out-LEM} - 1.65$$

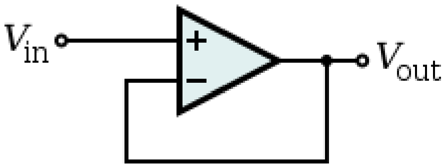


Figure 61 Op. Amp. Buffer

$$V_{out} = V_{in} = 2 \cdot V_{out-LEM} - 1.65$$

At the end, the same filter used in the voltage measure, filters noise and high frequencies.

The circuit uses the same op. amp. than the voltage so for the maximum error calculation the parameters are the same, resulting in a maximum error of:

$$V_{error} = V_{IO_1} + V_{IO_2} + V\left(I^+_{IO_1}\right) + V\left(I^-_{IO_1}\right) + V\left(I^+_{IO_2}\right) + V\left(I^-_{IO_2}\right)$$

As the offset have random values within those limits, the maximum function of error is (with the nomenclature of Figure 60):

$$V_{error} = V_{IO} \cdot \left(1 + \frac{R_3}{R_4}\right) + I_{IO} \cdot \left(\frac{(R_1 \cdot R_2)}{(R_1 + R_2)} + \left(\frac{R_3}{R_4} + 1\right) + R_{filter}\right) = 0.038625\ V$$

$$\varepsilon_{abs} = 0.03877\ V$$

$$\varepsilon_{rel\ end\ of\ scale} = \frac{0.03877\ V}{3.3\ V} \cdot 100 = 1.17\% < 5\%$$

4.3.3 MCU SOC CALCULATIONS

Once the measures have been taken, the MCU must reverse the signal adapting to get to the original values and calculate the real values. The goal is to obtain an estimation on the SoC of the battery in a range from 0% to 100%. It is considered the minimum of the battery voltage the nominal value of 36 V which is considered as a 15 % of charge capacity. The maximum of 100% of charging capacity is set at 42 V with nearly 0 A of current absorbed. The first step is to calculate the values of the battery measured:

$$V_{bat} = 14.4 \cdot V_{measuredADC1}$$

$$I_{bat} = 1.6\overline{18} \cdot V_{measuredADC2}$$

As it has been showed before in Figure 54, the SoC function is a non-linear function, so as a first approach, it has been defined as a piecewise linear function. There are two pieces in the function:

- First piece: constant current and increasing voltage are considered. The limit defined is close to the floating voltage of the charger at 41.5 V. In this interval the current is not considered, the lower limit of the function is 15% of charging capacity at 36 V and the upper limit is at 85% charging capacity with 41.5V.

$$SoC = 15 + 12.73 \cdot (41.5 - V_{bat})$$

- Second piece: constant voltage and decreasing drained current are considered. When 41.5 V are reached the piece of the function estimates the SoC considering only the current. The lower limit is set at 1.5 A charging current with a 85% of the charging capacity and the upper limit at 0.5 A charging current with a 100% of the charging current.

$$SoC = -15 \cdot I_{bat} + 107.5$$

Once this value is calculated, it is sent to the communications board through the communication interface.

4.3.4 QUANTIZATION ERROR

As the ADC used has a resolution of 10 bits, some information is lost due to the finite precision. To evaluate the whole error of the system this must be taken into account with the offsets of the op amps previously calculated.

$$\varepsilon_{quantization} = \frac{3.3\ V}{2^{10} bits} = 3.22 \cdot 10^{-3}\ {}^{V}\!/_{error}$$

$$\varepsilon_{abs} = \varepsilon_{quantization} \cdot Circuit\ Gain$$

4.3.4.1 Battery voltage

$$\varepsilon_{abs} = \varepsilon_{quantization} \cdot Circuit\ Gain = 3.22 \cdot 10^{-3}\ V \cdot 14.4 = 0.046\ V$$

$$\varepsilon_{rel\ end\ of\ scale} = \frac{0.046\ V}{42\ V} \cdot 100 = 0.11\ \% < 5\%$$

$$Total\ \varepsilon = 1.15 + 0.11 = 1.26\ \% < 5\ \%$$

4.3.4.2 Battery current

$$\varepsilon_{abs} = \varepsilon_{quantization} \cdot Circuit\ Gain = 3.22 \cdot 10^{-3}\ V \cdot 1.6\overline{18} = 5.21\ mA$$

$$\varepsilon_{rel\ end\ of\ scale} = \frac{5.21\ mA}{2.67\ A} \cdot 100 = 0.195\ \% < 5\%$$

$$Total\ \varepsilon = 1.17 + 0.195 = 1.365\ \% < 5\ \%$$

The total error in both measures is below the 5% which is within a very acceptable range. The effect on variances of components has been considered negligible as it is considered that there are enough components so that variations are compensated by themselves.

4.3.5 CHARGER FLOW CONTROL

In the version V1.0 of the control board a charger flow control was introduced. In case there should be charging control for any reason a relay to control the flow was added. It was designed as the door activation system which can be checked in detail in section 4.4.1.

4.4 ACCESS CONTROL

The access control consists of the door actuator and the Radio Frequency Identification (RFID) reader. The control board will asynchronously read and wait for a tag in the RFID reader, which will then send the ID obtained, check it with the access control server and wait for the response. If the response is an acknowledge (ACK), the control system will proceed to open the door. Then, we can divide the access control in two parts, the door control and the RFID reading. When the IT platform is developed it will complement the RFID access control with access through an app.

4.4.1 DOOR CONTROL AND AUTOMATION

In order to be able to work with any kind of industrial equipment existing in the market, the best way to activate the door is through a relay circuit. However, the MCU usually cannot supply enough current to activate a relay, so a transistor is used for this purpose. The selected relay is selected to work with 12 V in its coil, a standardised voltage for this application. In the signal pins with the transistor there will be 12 V too.

Initially, the selected transistors were of MOSFET technology, which require much less current from the MCU, but the selected ones were not suitable, so in order to reduce the number of different components in the board, they were substituted by bipolar junction transistors (BJT) with a NPN structure. They are the same as the ones used for the LED activation.

The relay characteristics for the circuit design are:

Parameter	Value
Rated Voltage	**12 VDC**
Rated Current	33.3 mA
Power Consumption	400 mW
Contact max current	10 A
Max switching voltage	124 VDC

Table 20 Door and charge flow control relay parameters

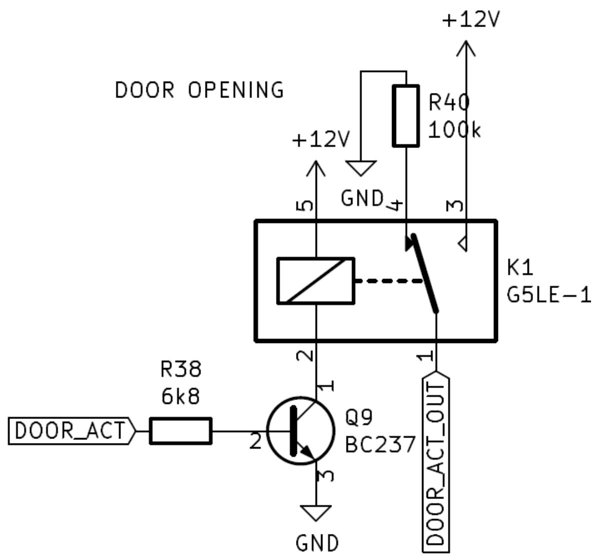


Figure 62 Door control relay circuit

In this case, the transistor will work in saturation mode too, as they are controlled as switches. So, to limit the current from the MCU to 0.38 mA the resistors needed in the base of the transistor are $R_b = 6.8\ k\Omega$

$$I_B = 0.38\ mA \qquad\qquad V_{DOOR\_ACT} = 3.3\ V$$

$$V_{DOOR\_ACT} - I_B \cdot R_{38} - V_{BE} = 0$$

$$R_{38} = 6.8\ k\Omega$$

$$I_C = 38\ mA$$

Figure 63 OMRON G5LE general purpose relay series

In addition to the door control relay, a magnetic sensor to know the status of the door was added. This sensor is fixed to the door frame and works as a switch which has an actuator fixed to the door and that activates the switch by proximity. It is a passive sensor, so it is ensured the compatibility with any existing and future system.

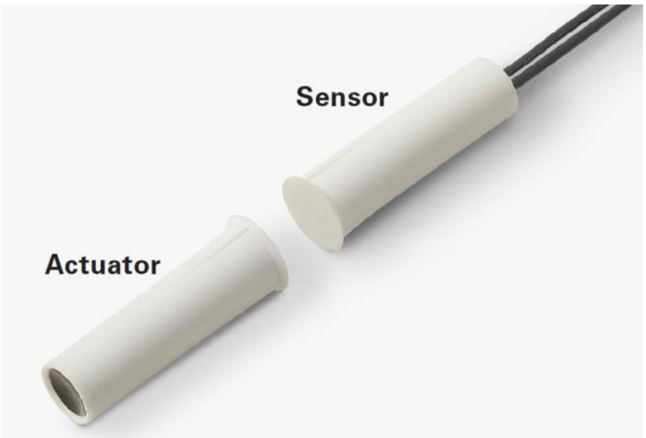


Figure 64 Door magnetic sensor

4.4.2 RFID READER CONTROL

The first approach to the access control has been to implement it with a RFID interface. For this purpose, it has been purchased a RFID reader with a serial interface from the manufacturer Parallax. It is an off the shelf solution that helps to develop innovative solutions quickly and easily. The device is compatible with any 125 kHz passive read only transponder and has the following connections:

Pin #	Pin Name	Pin Type	Function
1	VCC	POWER	System power. +5V DC input.
2	ENABLE	INPUT	Module enable pin. Active LOW digital input. Bring this pin LOW to enable the RFID reader and activate the antenna.
3	S OUT	OUTPUT	Serial output to host. TTL-level interface, 2400 bps, 8 data bits, no parity, 1 stop bit.
4	GND	POWER	System ground. Connect to power supply's ground (GND) terminal.

Table 21 Parallax RFID reader connections

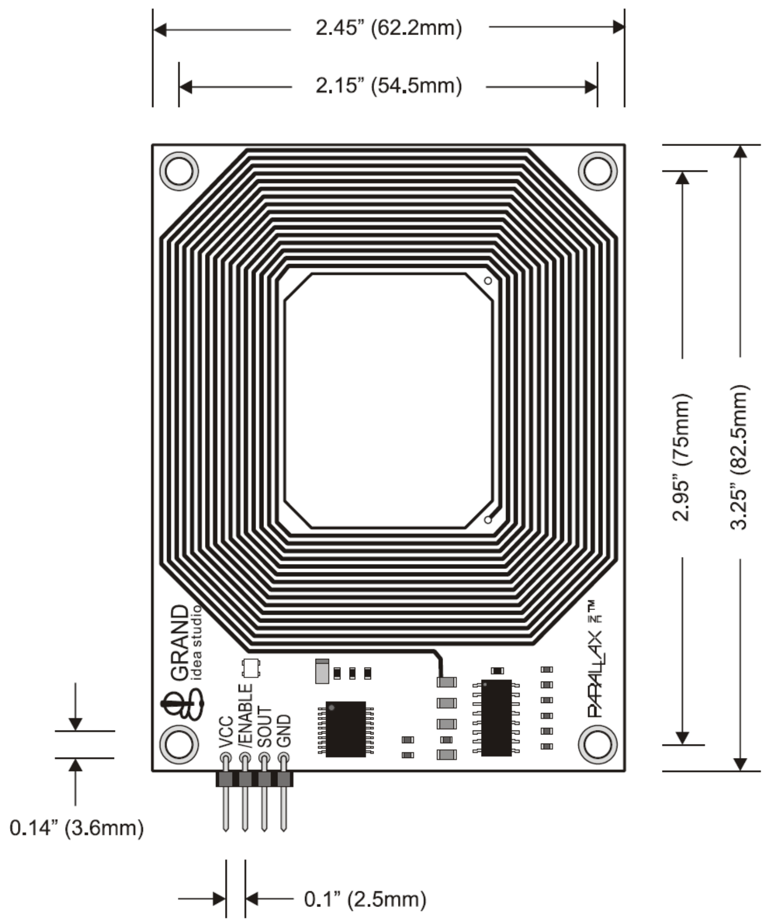


Figure 65 Parallax RFID serial interface reader

Figure 66 RFID transponder used for tests

4.4.2.1 Communications Protocol

The defined communication protocol by the manufacturer is a serial interface which is connected to one of the Universal Asynchronous Receiver and Transceiver (UART) of the MCU and that is configured as follows: 8 data bits, no parity, 1 stop bit, and least significant bit first (8N1) at 2400 bps. The RFID Card Reader Serial version transmits data as 5 V TTL-level, non-inverted asynchronous serial.

When the RFID Card Reader is active, and a valid RFID transponder tag is placed within range of the activated reader, the tag's unique ID will be transmitted as a 12-byte printable ASCII string serially to the host. The start byte and stop byte are used to easily identify the start and stop of the message (they correspond to line feed and carriage return characters, respectively). The middle ten bytes are the actual tag's unique ID.

Header	ID	End of Message
0x0A	10 bytes	0x0D

Table 22 RFID tag message transmission format

It is recommended by the manufacturer that in order to avoid false readings due to interferences to wait at least for two consecutive readings and then transmit the last one.

However, the RFID reader works at 5 V, while the MCU works at 3.3 V, so an additional circuit has been added to adapt these levels. Fortunately transmission speeds are not very high, so a circuit has been built with MOSFET transistors resulting in a flawless transmission

This circuit has been extracted from the SparkFun Electronics [35] open source repository and is a bidirectional solution for communications and signals with has had very good result and that is compatible with various voltage levels.

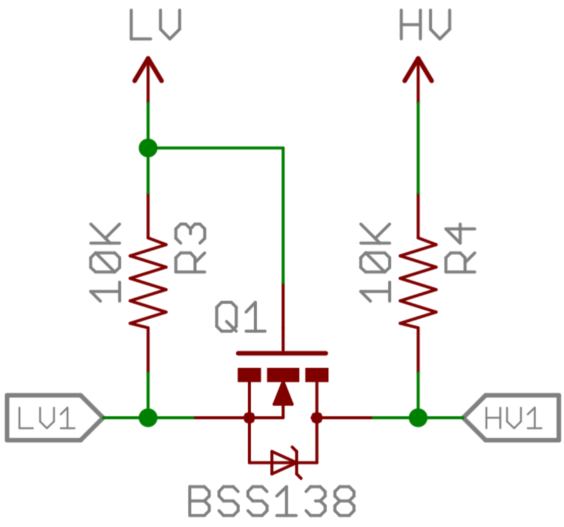


Figure 67 Bidirectional logic level converter schematic

To read the data from the serial output, the UART2 is used and it is configured accordingly to the reader protocol and set to work through interruptions. This configuration is described in detail in section 4.4.3.

4.4.3 ACCESS CONTROL PROGRAMMING

A different class file has been developed to control the door. This class initialises the inputs and outputs, configures the necessary peripherals and triggers the send of the information to the communications board. The door control task uses two peripherals: one timer to control the opening time of the door and a UART to receive the tag ID from the reader.

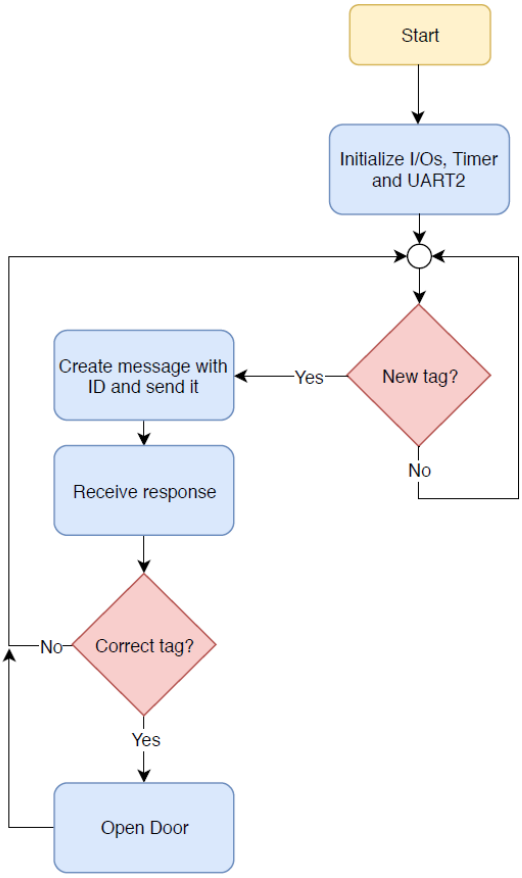


Figure 68 Door control program flow

The C script module that manages the door contains the following functions:

```
void initDoorAct(void);
void doorControl(void);
```

The function *initDoorAct()* is the function in charge of initialising the I/Os, configuring the pins and starting the different peripherals: the timer for timing the door opening, and the UART interface to communicate with the RFID reader.

The function *doorControl()* receives asynchronously a flag when a tag ID is received, then sends the tag to the communications board and wait for response. Once the response is received, it will check the content and if access is granted will open the door during certain time

4.5 COMMUNICATIONS INTERFACE

The control board both UARTs from the MCU. One of them (UART2) is used to communicate with the RFID reader, and the other one (UART1) is used to communicate with the local communications network. For this purpose, the system will use a multi-point network standard which is widespread in industry: the RS485 standard. Consequently, a transceiver is needed to translate from RS232 (UART) standard to RS485 standard. It was selected the SN65HVD12 transceiver from the manufacturer Texas Instrument. The whole communications system ant it's architecture is described in detail in CHAPTER 5. In this section only the circuit for the control board is explained.

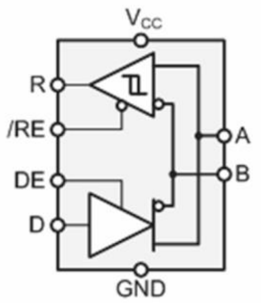


Figure 69 SN65HVD12 Texas Instrument RS485 transceiver block diagram

Following the manufacturers recommended configuration the circuit used for the transceiver is shown in Figure 70 and it has been set on a configuration to work as a listener or a sender alternatively by setting or resetting the control bit DIR_COM. The standard sets that at each extreme of the network there must be a resistor to guarantee the impedance of the line, so to easily set a node as the end of the network there has been added a jumper to set the resistor at a value of 120 Ω .

The standard also recommends having a fail-safe biasing with resistors to avoid undefined voltage levels when no driver is actively driving the bus. This biasing is only required in one point of the network, which has been determined as the common node in every network of the MOD-Hub, the communications board. [36]

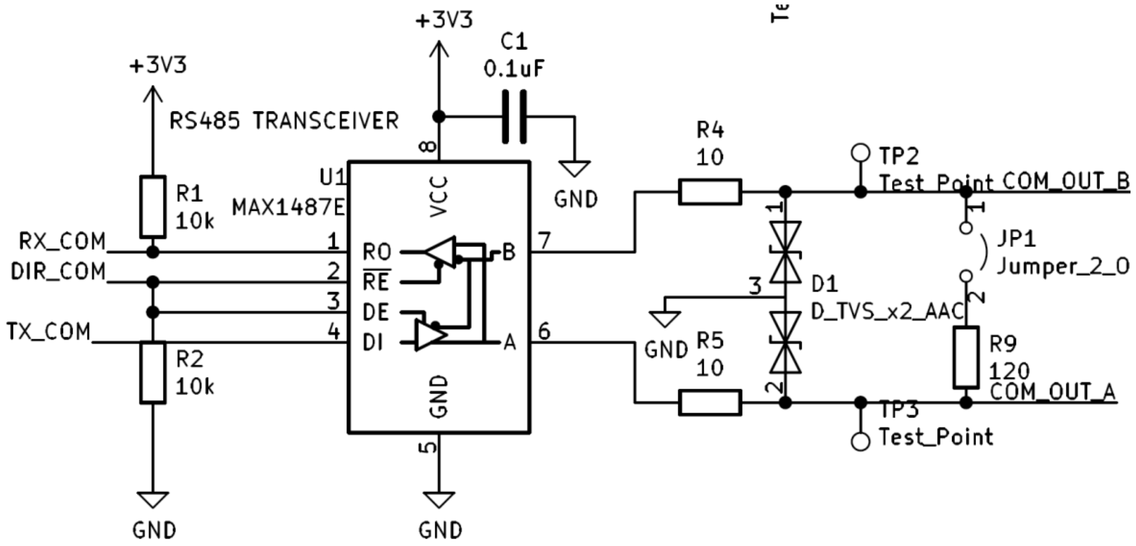


Figure 70 Transceiver circuit of the control system

The setting for both UARTS of the control system are as follows:

	Data bits	Parity	Stop bits	Data format	Baudrate	Function	Voltage level
UART1	8	NO	1	Little endian	38400	Communications	3.3V
UART2	8	NO	1	Little endian	2400	RFID reader	5V

Table 23 UARTs configuration control board

CHAPTER 5. COMMUNICATIONS SYSTEM

Communication is vital for the MOD-Hub. Through connectivity real-time information is gathered to provide the better service to the user. A communications board has been developed to carry out this task. This board may be less complicated in terms of hardware as it has to use less peripherals and only take over one task (communications), but in terms of computing workload and software its complexity it is higher than the control system, as it has to deal with messages to/from modules and to/from the server. The schematics of the board can be consulted in **¡Error! No se encuentra el origen de la referencia.**.

5.1 GENERAL STRUCTURE OF THE COMMUNICATIONS SYSTEM

To achieve flexibility and having a low-cost solution the communication system has been designed to use only one communications board per site. This is possible by creating a local network in every location using the industrial standard RS485 and then using mobile or Wi-Fi a a gateway to connect to the server. The general architecture of the communications system is shown in Figure 71.

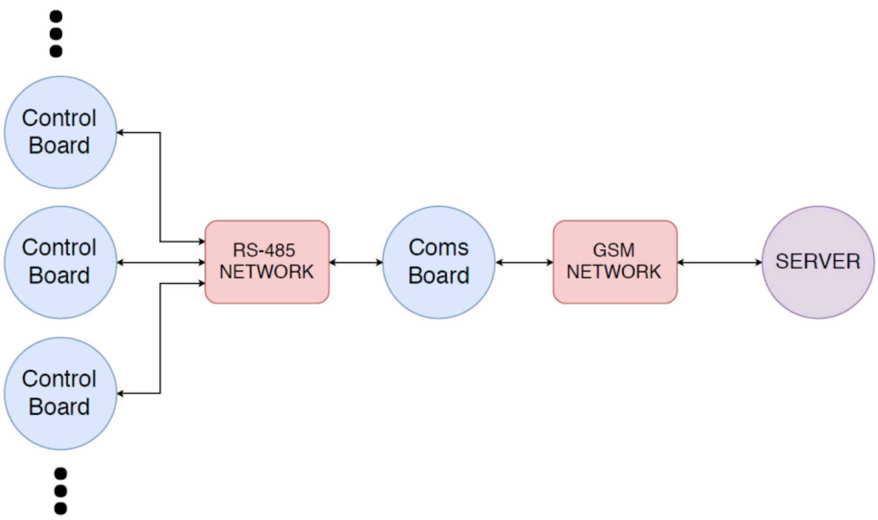


Figure 71 Communications architecture of the MOD-Hub

5.2 MICROCONTROLLER

The system is based in the same MCU than the control system: PIC32MX174F256B. and the pin layout is as follows:

PIN number	Function	I/O	PORT	FUNC TYPE	PIN TYPE
1	MCLR	I/O	-	RESET	RESET
2	TX_COM	O	RA0	U1TX	RPA0
3	GSM_RX	I	RA1	U2RX	RPA1
4	GSM_PWRMON	I	RB0	RB0	RB0
5	GSM_RTS	O	RB1	RB1	RB1
6	GSM_CTS	O	RB2	RB2	DIO
7	GSMP_PWM	O	RB3	RB3	DIO
8	VSS	-	-	POWER	POWER
9	RX_COM	O	RA2	U1RX	RPA2
10	GSM_TX	O	RA3	U2TX	RPA3
11	GSM_PWRKEY	I	RB4	RB4	DIO
12	DIR_COM	I/O	RA4	RA4	DIO
13	VDD	-	-	POWER	POWER
14	LED01	O	RB5	RB5	DIO
15	LED02	O	RB6	RB6	DIO
16	SW01	I	RB7	RB7	DIO
17	NC	-	RB8	-	-
18	NC	-	RB9	-	-
19	VSS	-	-	POWER	POWER
20	VCAP	-	-	POWER	POWER
21	PGED1	I/O	RB10	PGED1	ICSP
22	PGEC1	I/O	RB11	PGEC1	ICSP
23	NC	-	RB12	-	-
24	NC	-	RB13	-	-
25	NC	-	RB14	-	-
26	NC	-	RB15	-	-
27	AVSS	-	-	POWER	POWER
28	AVDD	-	-	POWER	POWER

Table 24 Pin list of MCU in the communications board

The configuration of the MCU is the same as for the control board and can be seen in Section 4.2. Alternatively, different test points have been added to be able to debug communications more easily.

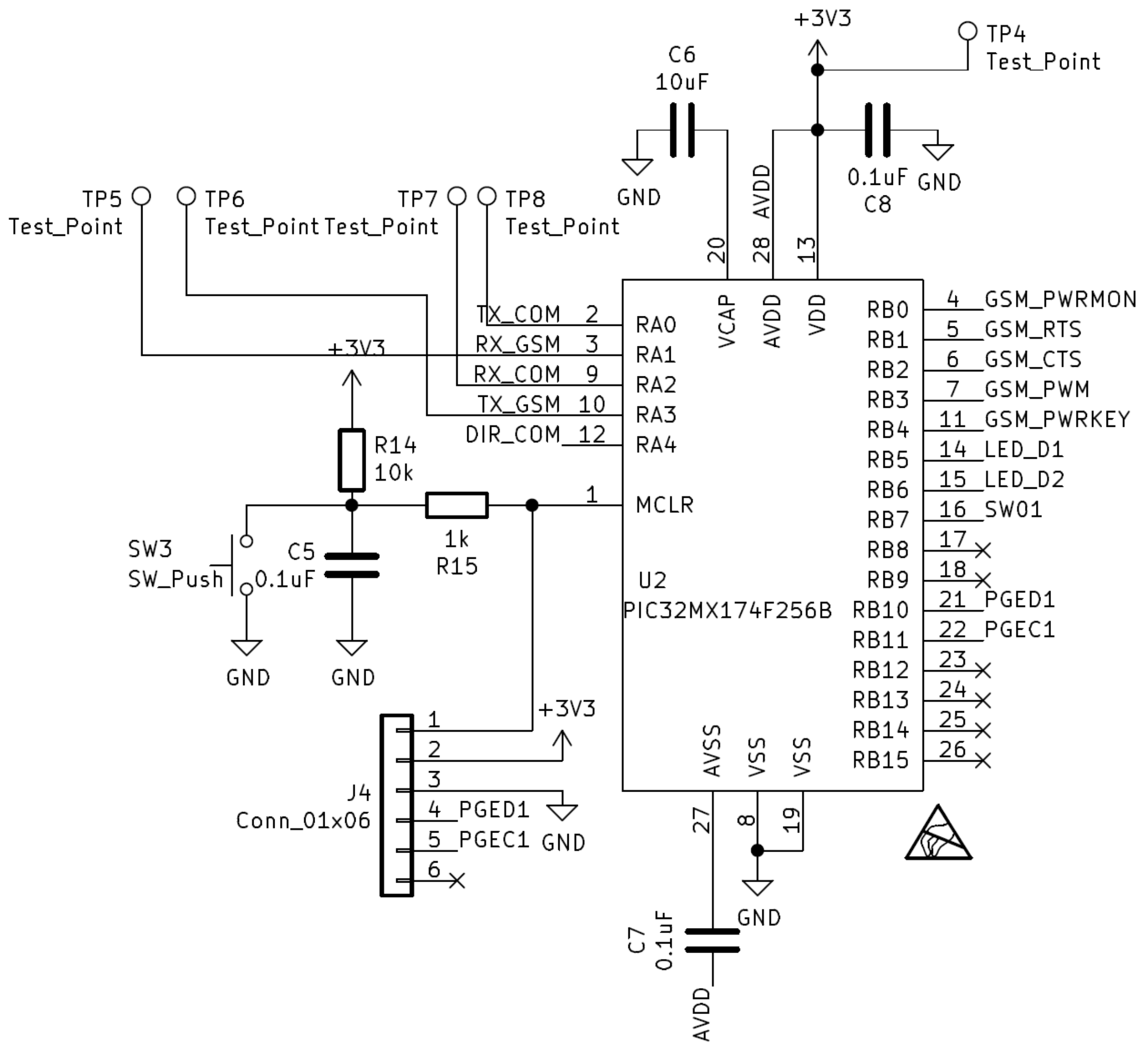


Figure 72 PIC32MX174F256B schematic in the communications board

5.2.1 POWER SUPPLY

For the communication board only one power supply is needed as all of the components work at the same voltage (3.3V). As in the control board, a power LED has been added to check for malfunctions.

Voltage	3.3V
Application	MCU, control of relays, SoC metering circuits, communications circuits
Estimated consumption	4W
Selected model	IRM-05-3.3

Table 25 Power supply estimations for the communications system

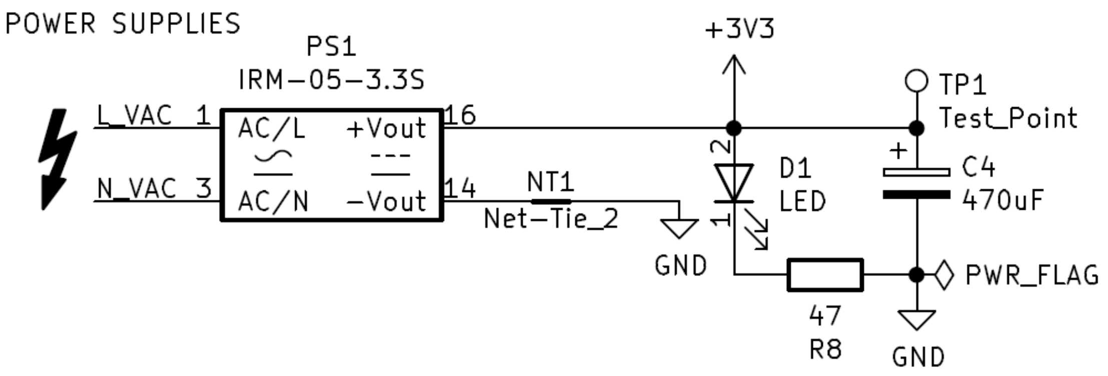


Figure 73 Power supply for the communications board

5.2.2 TESTING LEDS AND SWITCHES

In this board is extremely important too to be able to test and have ways of simulating inputs and outputs, so two LEDs and one switch have been added following the same design process as for the ones in the control board.

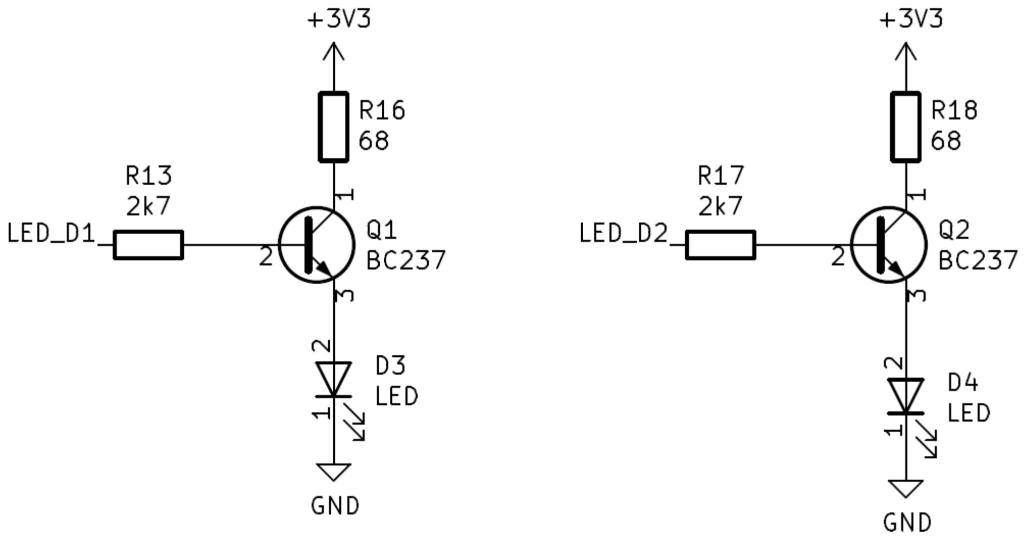


Figure 74 Test LEDs in the communications board

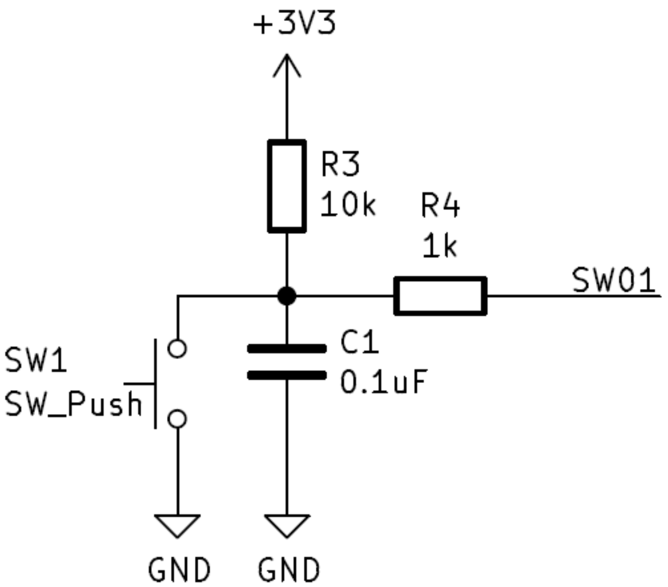


Figure 75 Test switch in the communications board

5.3 COMMUNICATIONS INTERFACE

The communications from the MCU use both of the UARTS; UART1 is used to connect to the RS485 transceiver with the rest of the modules, while the UART2 in this case is used to communicate with the external communications module, which is compatible with both GSM or Wi-Fi modules. This compatibility is because a specific connector standard has been used to be able to connect to a number of different boards and only having to change the software: the MikroBus standard [37].

In this board, fail-safe biasing is for the RS-485 network is added with resistors.

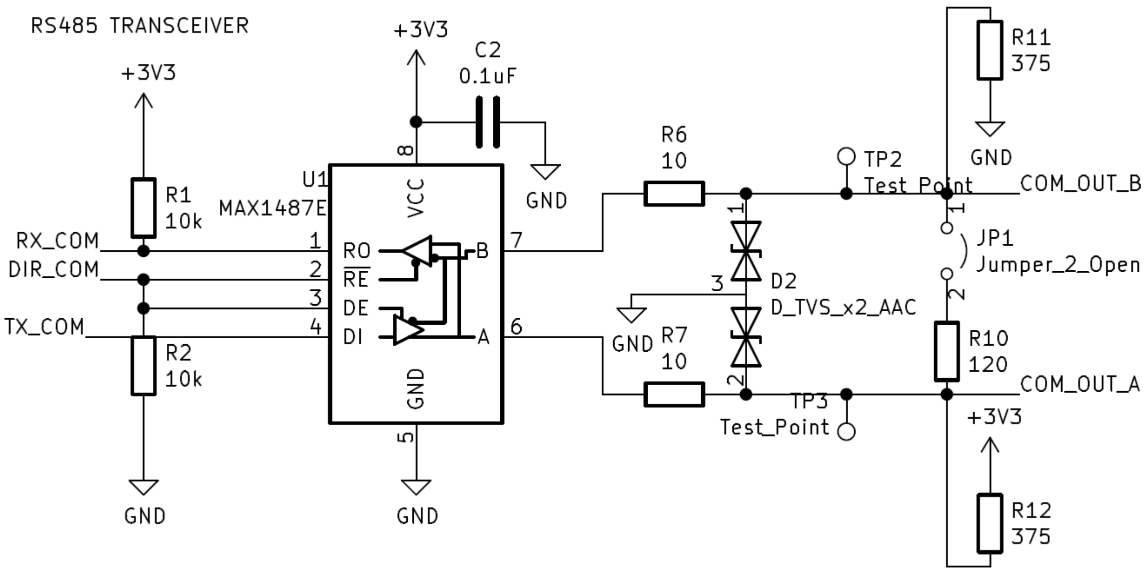


Figure 76 RS-485 transceiver circuit of the communications board

5.3.1 MIKROBUS STANDARD

The MikroBus standard is a socket standard that comprises a pair of 1x8 female headers with a proprietary pin configuration and silkscreen markings. The pinout (always laid out in the same order) consists of three groups of communications pins (SPI, UART and I2 C), six additional pins (PWM, Interrupt, Analog input, Reset and Chip select), and two power groups (+3.3V and GND on the left, and 5V and GND on the right 1x8 header).

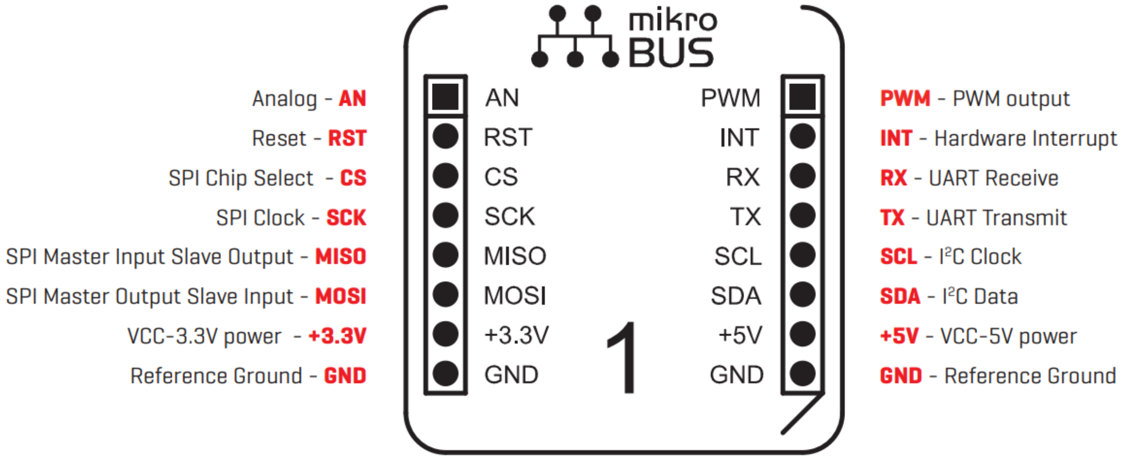


Figure 77 MikroBus socket standard layout [37]

For the specific version of the communications board the GSM module was used, as it offers more connectivity and security in transmissions. Wi-Fi would require of an additional layer of security for communications. More specifically, the GSM module used is the Mikroe GSM2 Click Board from MikroElektronica.

5.4 GSM COMMUNICATIONS MODULE

The idea behind using a mobile network module was to be able to transmit data from nearly anywhere without depending on the existence of a Wi-Fi network. Additionally, as the data transmitted are small data packages, GSM (2G) technology offers more than enough transmission speed. The used GSM module offers an uplink and downlink speed of 85.6 kbps. Messages from modules have a length of up to 32bytes, which are 256 bits. This means that with the GSM module, we could send up to 337 messages per second. Bearing in mind that we would send the battery SoC every 10 seconds at most, and for access only one message would be needed this makes the transmission speed more than enough for our purpose.

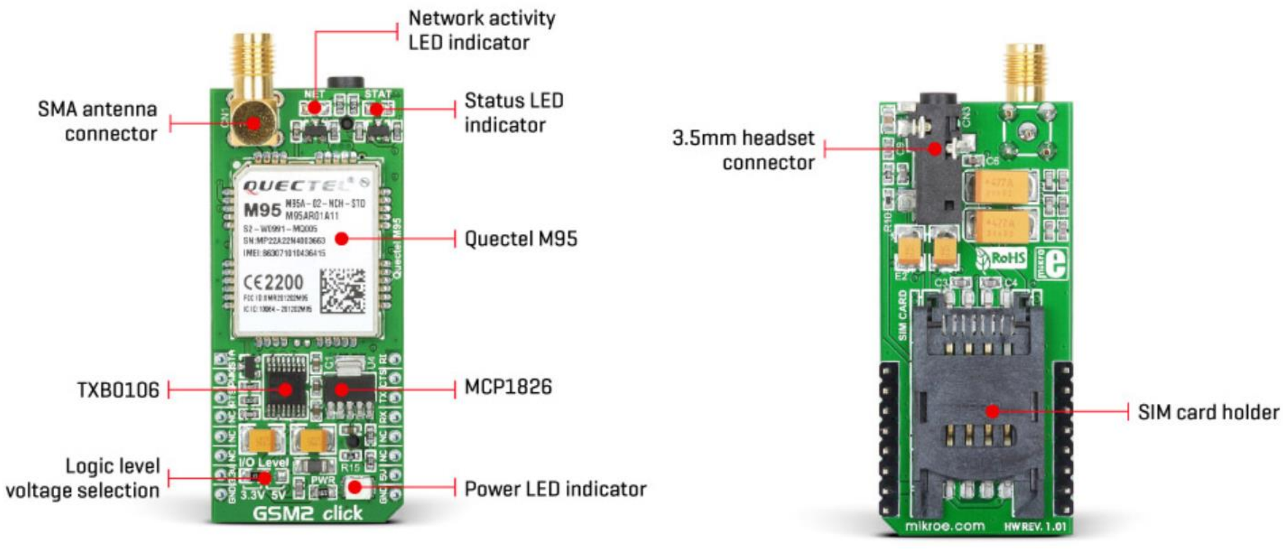


Figure 78 Mikroe GSM2 module [38]

The pins of the module are shown in Table 26.

Notes	Pin	mikroBUS				Pin	Notes
Indicates the module's operating status	**STAT**	1	AN	PWM	16	**RI**	Ring indication
Power on/off key	**PWRKEY**	2	RST	INT	15	**CTS**	Clear to send
Request to send	**RTS**	3	CS	RX	14	**TXD**	Transmit data
	NC	4	SCK	TX	13	**RXD**	Receive data
	NC	5	MISO	SCL	12	NC	
	NC	6	MOSI	SDA	11	NC	
Power Supply	**+3V3**	7	3.3V	5V	10	**+5V**	Power Supply
Ground	**GND**	8	GND	GND	9	**GND**	Ground

Table 26 Mikroe GSM2 module pins [38]

This module counts with a library, developed by MikroElektronika, with the necessary APIs to work fast and have an easy integration with other systems. [39]

5.5 COMMUNICATIONS PROGRAMMING

The MCU in the communications system receives messages and transforms them into the corresponding data to transmit them into their destinies network, so when they receive an opening command from a MOD-Hub module, they extract the valuable data and format it for the server and the GSM module; when it receives a message from the server, again it extracts the valuable data and adapt it correctly for the RS485 network. As communications interface the MCU uses its both UARTs, whose configuration is as follows:

	Data bits	Parity	Stop bits	Data format	Baud rate	Function	Voltage level
UART1	8	NO	1	Little endian	38400	RS485 communications	3.3V
UART2	8	NO	1	Little endian	38400	GSM module	3.3V

Table 27 UARTs configuration communications board

It was found out during tests, that with baud rates over 38400 the messages would reach corrupt to the receiver, so the baud rates were limited to 38400. This has a possible origin on the length and path of the routes that creates parasite impedances that interfere in transmissions.

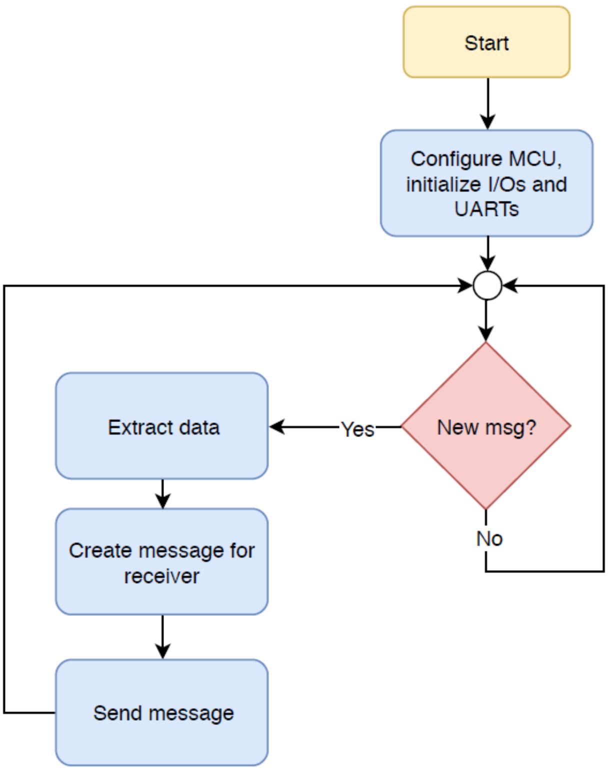


Figure 79 Communications program flow

CHAPTER 6. ENERGY MANAGEMENT SYSTEM

6.1 INTRODUCTION

In this chapter the energy angle of the MOD-Hub is analysed. How to ensure continuous operation when the main energy source fails and alternatives to have a sustainable and energetically independent product.

6.2 ENERGY USE

Power supply cannot always be provided to bike storage platforms and availability depends on the local conditions for the system (infrastructure limitations, non-permanent e-Hubs…). As one possible solution, solar energy harvesting through photovoltaic panels (PV) could be added to the modules to obtain clean energy from an independent source. Additionally, where power is available, the system could be integrated with the grid to reduce total consumption and consequently reducing operation costs. Other possible solution would be to have a backup system in case the grid had a power cut.

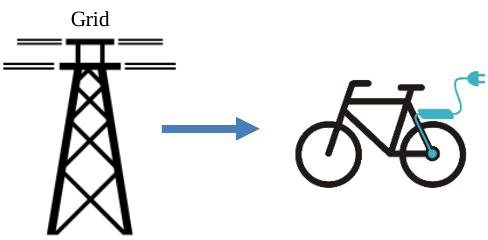


Figure 80 Actual energy system

The different alternatives for energy management and solar energy supply are analysed now.

6.2.1 OFF-GRID SYSTEM

The elements that conform a totally off-grid installation are the following:

- PV panels to obtain the energy form the sun.
- Batteries. For days when there is no sun or for night operation, a set of batteries would be needed.
- Batteries controller. To ensure a safe charge and discharge of the battery a battery monitor is needed.
- DC to DC converter. This device stabilizes the power input from the panels and sets it to the adequate load requirements.
- DC to AC converter (inverter). If the e-bike is going to use its own charger with a regular plug, an inverter is needed. However, the bike could be charged directly from the solar batteries with a different charger.

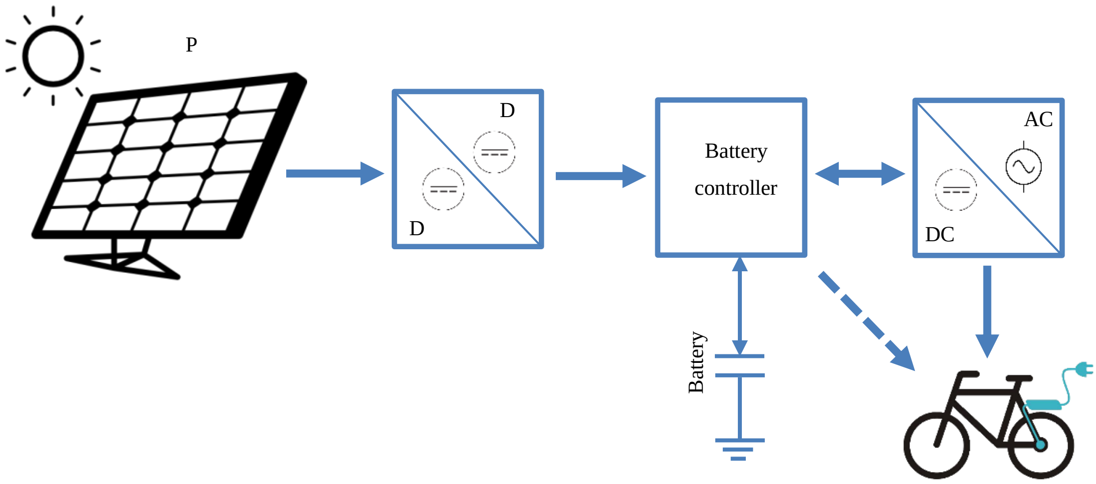


Figure 81 Photovoltaic energy system off-grid

6.2.2 GRID SUPPORTED SYSTEM

The PV system could be integrated with the grid so that when neither the panels or the batteries have enough power capacity, the grid would feed the load as needed or charge the batteries. However, in order to the PV system to inject spare energy into the grid certain requirements must be met.

In this case the elements needed are the same than for an off-grid set up but with additional devices:

- In this case the AC to DC converter (inverter) is not optional.
- An AC transfer switch to control the extraction or injection of power from the grid.

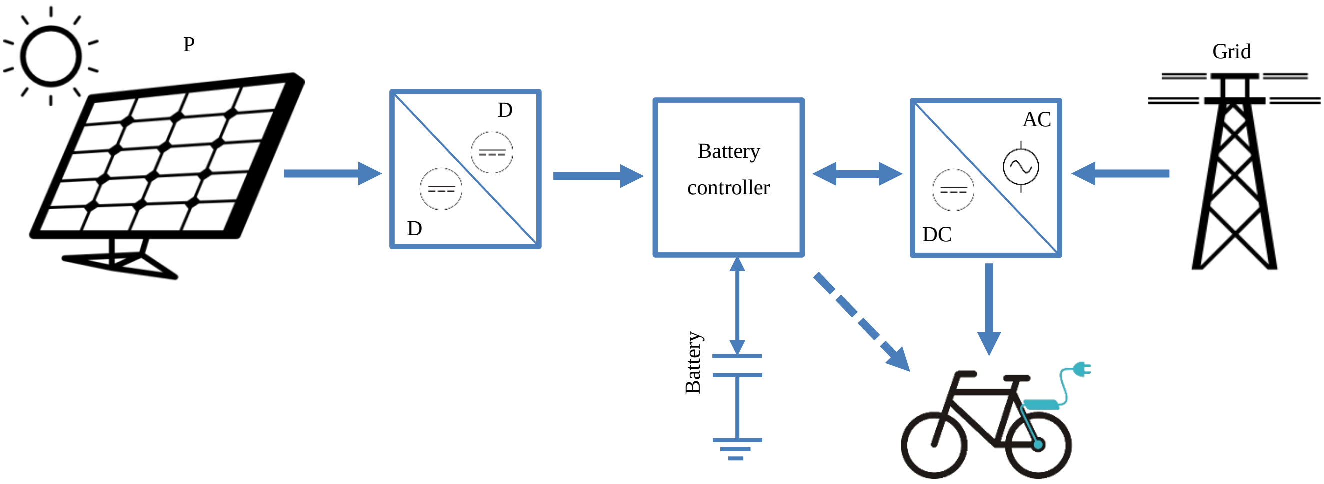


Figure 82 Photovoltaic energy system with grid support

6.2.3 GRID CONNECTED WITH BACK-UP SYSTEM (UPS)

Finally, an uninterruptible power supply (UPS) could be implemented to serve as a back-up for the MOD-Hub in case there was a power cut.

The elements for this system would be:

- An AC to DC converter (rectifier). It adapts the grid voltage to the battery.
- Battery controller.
- An DC to AC converter (inverter). In this case this is optional and depends on the charger for the e-bike.

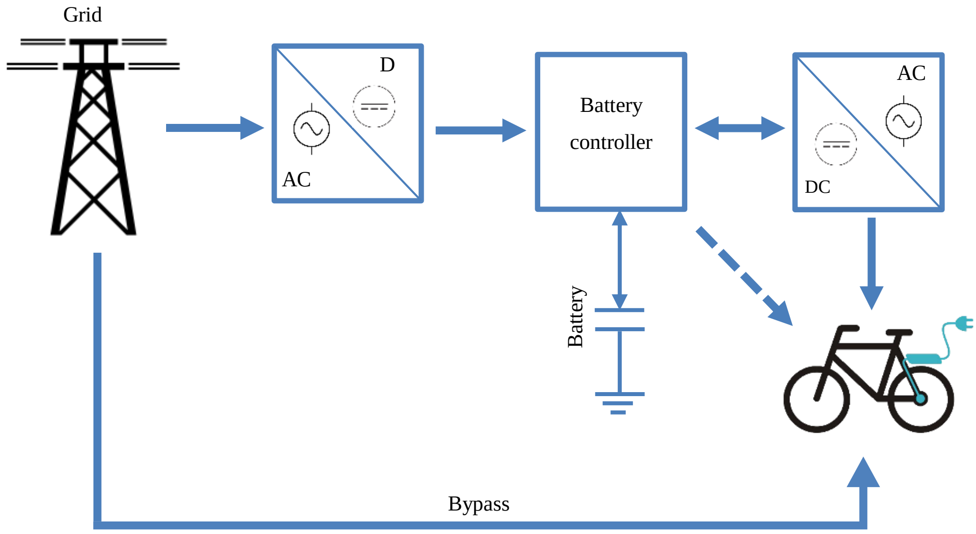


Figure 83 Uninterruptible power supply with grid

6.3 CONSUMPTION AND IRRADIATION ANALYSIS

In order to determine the size of the used equipment, an analysis of the requirements of the system has to be made: the loads have to be characterised and the energy generated by the panels has to be calculated.

The approach of the study is to make every single module of the MOD-Hub energetically independent, so that MOD-Hub reconfigurations are made easily.

Another possible approach would be to make a PV installation that can supply a number of modules, but this would limit the adaptability and flexibility of the product.

6.3.1 CONSUMPTION

First of all, the electrical loads must be determined to be able to set the PV requirements. The following electrical parameters of MOD-Hub modules have been considered.

EBIKE	
Max Voltage Charger	40 V
Max Current Charger	2 A
Electric charge	10 Ah
Battery voltage	36 V
REST OF SYSTEM	
Power Consumption	20 W

Table 28 Energy consumption estimation parameters

6.3.2 POWER

The minimum power that the installation needs to generate for the system depends on the power that the chargers consumes and the power of the equipment to manage the system. This value represents the minimum power generated for a totally autonomous installation. If it is lower, there must exist grid support when consumption rises.

$$P_{PV} = P_{bike\ charger} + P_{sys}$$

$$P_{bike\ charger} = V_{charger} \cdot I_{charger} = 40\ V \cdot 2\ A = 80\ W$$

$$P_{sys} = 0{,}2 \cdot P_{bike\ charger}\ W$$

$$P_{PV} = 100\ W$$

6.3.3 ENERGY

Providing that each locker will have to charge the equivalent of 1 full battery a day, and that the energy consumed by the system is 20% of the energy needed for a battery charge, the total **energy** that will have to be produced daily is:

$$E_{1day} = E_{sys} + E_{battery}$$

$$E_{battery} = Electric\ charge \cdot Battery\ voltage = 10\ Ah \cdot 36\ V = 360\ Wh$$

$$E_{sys} = 0{,}2 \cdot E_{battery} = 90\ Wh$$

$$E_{1day} = 450\ Wh$$

6.3.4 SOLAR IRRADIATION

The sun is not the same in every place so that it is why for the selection of the PV panels, the characteristics of where is going to be deployed must be known. The most important data to be known is the solar irradiation, which shows the energy produced by surface unit (Wh/m^2). Two cities are going to be analysed: Rome and Málaga.

For the design of the panel power the worst scenario criteria will be used, that is, the month with the less irradiation will be used as design parameter. Additionally, it will be considered that the panel is fixed horizontally.

6.3.5 MÁLAGA

Málaga is one of the places in Spain with the most hours of sun a year and more solar irradiation received.

The average daily irradiation data for each month is the following:

Month	H_h (Wh/m²/day)	H_{opt} (Wh/m²/day)	I_{opt} (°)
Jan	2710	4530	62
Feb	3610	5270	54
Mar	5110	6280	40
Apr	5940	6310	26
May	7050	6700	10
Jun	8000	7170	2
Jul	7970	7330	6
Aug	7080	7220	19
Sep	5510	6490	35
Oct	4210	5780	49
Nov	2900	4660	60
Dec	2380	4130	64
YEAR	5210	5990	33

Table 29 Málaga average irradiation per day [40]

H_h: Irradiation on horizontal plane (Wh/m^2/day)

H_{opt}: Irradiation on optimally inclined plane (Wh/m^2/day)

I_{opt}: Optimal degree of inclination (°)

6.3.6 ROME

Rome has smaller values of irradiation than Málaga as can be seen in the following table:

Month	H_h (Wh/m²/day)	H_{opt} (Wh/m²/day)	I_{opt} (°)
Jan	1800	3060	64
Feb	2810	4290	57
Mar	4140	5240	44
Apr	5310	5840	29
May	6540	6420	15
Jun	7480	6960	8
Jul	7750	7390	12
Aug	6720	7150	25
Sep	4900	5990	39
Oct	3400	4780	52
Nov	2100	3460	62
Dec	1630	2980	66
YEAR	4560	5300	35

Table 30 Roma irradiation average per day [40]

H_h: Irradiation on horizontal plane (Wh/m^2/day)

H_{opt}: Irradiation on optimally inclined plane (Wh/m^2/day)

The worst month is December in Rome, so it will be used as reference for the calculations.

6.4 SYSTEM REQUIREMENTS

6.4.1 PV PANELS

As a general requirement, photovoltaic panels cannot exceed the dimensions of the e-Hub roof size.

For the panels a security factor $\alpha = 1{,}1$ will be used to set the required power. This factor represents the relation between energy produced by the PV panels, and the demanded energy.

$$\alpha = \frac{E_{produced}}{E_{demand}} = \frac{P_{PV} \cdot {}^{H_h}/_{I_{STC}}}{E_{sys}}$$

$$1{,}1 = \frac{P_{PV} \cdot {}^{1630}/_{1000}}{450}$$

$$P_{PV} = 303\ W$$

$I_{STC} = 1000\, W/m^2$ - Irradiance Standard Test Conditions [41]: Standard Test Conditions create uniform test conditions which make it possible to conduct uniform comparisons of photovoltaic modules by different manufacturers. The test conditions are defined as follows - irradiation: 1000 W/m², temperature: 25°C, AM: 1,5 (AM stands for Air Mass, the thickness of the atmosphere; at the equator, air mass = 1, in Europe approx. 1,5).

A correction factor of $\beta = 0{,}65$ is used to consider the power losses and the power needed for operation of the devices. The resulting power of the PV panel should be:

$$P_{PV\_REAL} = \frac{P_{PV}}{0{,}65} = 470W$$

Note that for the average solar irradiation: $\overline{H_h} = 4550\ {}^{Wh}/_{m^2 \cdot day}$ the required power is P_{PV_REAL}=167 W so a 200 W panel would be enough.

For a peak sun month in summer $H_h = 6500\,{}^{Wh}/_{m^2 \cdot day}$ which requires a P_{PV_REAL}=117 W, which would require a 120 W panel.

6.4.2 BATTERIES

The accumulators for the PV installation will have to be able to store the necessary energy for a day operation. As the MOD-Hubs are aimed for commuting, distances travelled will be short, so the estimated daily use of the bikes is of less than one complete charge.

For different voltages the required electrical charge of the batteries would be:

$$Electric\ charge = \frac{E_{sys}}{Battery\ voltage}$$

Battery voltage (V)	Electrical capacity (Ah)
12	37,5
24	18,75
36	12,5
48	9,375

Table 31 Battery capacities needed

6.5 INSTALLATION

Once we have the minimum requirements for the installation there are several possibilities according to the available products in the market.

For any kind of installation made the essential equipment are the panels and the batteries. Depending on the type of functionalities wanted different equipment is needed which has variants and different costs. The shown costs are extracted from different solar on-line stores [42]. The essentials estimation cost:

Element	Cost
Solar panel 200W	150 €
Battery 12V 50Ah	140 €

Table 32 Estimation cost PV+Battery

Standard size of panels is approximately 1,6mx1mx0,1m so only one panel could be fixed per module.

That battery prize is for one Li-Po block battery, but an option is to build batteries from smaller and cheaper cells of Lead-Acid or Li-Ion. with this technology a 50% price reduction could be achieved.

6.6 COMPLETE OFF-GRID

In the case the modules work as an off-grid installation it makes the implementation simpler, but the installation less reliable. The required equipment is a solar charge controller and an inverter.

- Solar charge controller. It task is to look after the batteries when charging and discharging. There are two main methods for extracting energy from the panels: MPPT or PWM. The PWM technology costs less but it is less efficient [43].
    - Victron BlueSolar PWM: 35 €
    - Victron BlueSolar MPPT 75/15: 80 €
    - Generic/Chinese solar charger PWM controller: 15-20 €

- Inverter. There are many different options with different powers, for example:
    - Xantrex 12V-150W: 40€ [44]
    - Xantrex 12V-300W: 52€

6.7 GRID SUPPORTED INSTALLATION

A layout with backup from the grid makes the costs are higher because of the additional equipment and intelligence required. There exist either totally integrated solutions, or by separate parts. The additional equipment needed compared to an off-grid installation is an automated transfer switch to be able to change the source of power from the batteries to the AC network.

6.7.1 ALL-IN-ONE CHINESE EQUIPMENT

There exist Chinese suppliers of all-in-one equipment: inverter, battery charger and automatic transfer switch.

- Sigineer 600 W to 220 VA power inverter charger: 122 €. This device has connectivity capabilities through a monitoring board and a serial interface. [45]

Figure 84 Sigineer all-in-one

6.7.2 ALL-IN-ONE EUROPEAN EQUIPMENT

Alternatively there are European suppliers of all-in-one equipment.

- Victron Energy MultiPlus 500 VA: 485 €. This device has connectivity through the manufacturer communications interface. [46]

Figure 85 Victron Energy MultiPlus all-in-one

6.7.3 AUTOMATED TRANSFER SWITCH

An alternative is adding to the off-grid option a separate automated transfer switch. However, for our required powers, there is very limited offer in the market and often with high prices.

- Victron Energy. Filax 2: 320 €

Figure 86 Victron Energy transfer switch

6.7.4 CUSTOM EQUIPMENT

Finally, custom equipment could be developed in order to obtain the lowest cost per unit but as it is a complex and multidisciplinary system it would require lot of resources committed to the development with a lot and uncertainty in the results.

6.8 UNINTERRUPTIBLE POWER SUPPLY

As shown earlier in this chapter, the required equipment is: rectifier, battery controller and the inverter. It is not uncommon to find a battery controller built within the rectifier.

- Rectifier+battery controller. Different possible suppliers:~200€
- Inverter. There are many different options with different powers, for example:
    - Xantrex 12V-150W: 40€

- Xantrex 12V-300W: 52€

6.9 ALTERNATIVES COMPARISON

In the following table the main characteristics and prices of the main alternatives proposed can be compared.

	All-in-one EU	All-in-one China	Off-Grid	UPS
Equipment cost	485 €	160 €	130 €	250 €
Batteries	140 €	140 €	140 €	140 €
PV	150 €	150 €	150 €	NA
Energy back-up	Yes	Yes	No	Yes
TOTAL	775 €	450 €	420 €	390 €
Supplier	Europe	China	Europe/China	Europe/Chine
Communication capability	Yes	Yes	Depends on selected equipment	Depends on selected equipment
Efficiency	90%	80%	Depends on selected equipment	Depends on selected equipment

Table 33 Alternative installation comparison

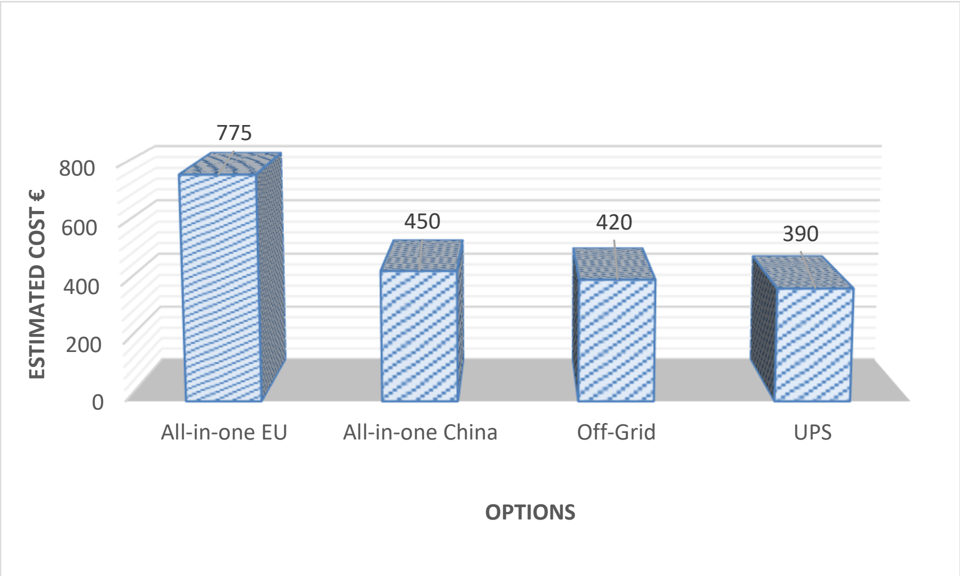


Figure 87 Cost comparison of alternative installations

6.10 ELECTRICITY COST AND FINANCIAL ANALYSIS

A key factor to be analysed is the cost of electricity generated by the system and how much electricity would the PV system save to reach the breakeven point.

Prices of electricity vary from one country to another because of their different energetic production mix. For example, France has a great amount of nuclear power which makes prices lower, while Italy has a big share based on fossil fuels, so they greatly depend on the price of them. Spain, on the contrary, has a balanced mix which helps to maintain prices stable. The average prices of electricity for non-household consumers in the last 2 years in Spain and Italy are:

Electricity prices for non-households (€/kWh)			
Country	**2016s1**	**2016s2**	**2017s1**
Spain	0,1051	0,0979	0,1010
Italy	0,0842	0,0879	0,0829

Table 34 Electricity prices for non-household consumers [47]

Considering the electricity prices from the last semester of 2017 the estimated cost of operation for a MOD-Hub with fourteen lockers is:

Country	**Power (kW)**	**Price of power (€/kW)**	**Energy a year (kWh)**	**Consumption price (€/kWh)**	**Modules**	**Total Power (kW)**	**Total energy a year (kWh)**	**Cost per module (€)**	**Total yearly cost (€)**
Spain	0,1	38,04	164,25	0,1010	14	1,4	2299,5	20,39	285,51
Italy		23,00		0,0829				15,92	222,83

Table 35 Electrical fares comparison Spain and Italy

6.11 PROFITABILITY OF THE SOLAR INSTALLATION

Integrating solar panels with the installation can not only make the system independent from the grid, but even can inject the extra generated power and receive a revenue from it. An analysis has been made considering an e-Hub that consists of 14 modules with 14 panels of 220W.

In Spain any solar generation under 10kW with accumulators must pay a tax depending on the power generated and the contracted power. Also, mandatory measurement equipment must be installed in certain points of the installation. This fare is approximately of 8,7 € per kW a year [48] [49] [50].

$$Solar\ tax = 8{,}7\ {}^{€}/_{kW\ a\ year} \cdot 1{,}4\ {}^{kW}/_{eHub} = 12{,}18\ {}^{€}/_{year\ eHub}$$

Additionally, if we considered that the non-used energy is sold at market price, if the average price is 5c€/kWh [47] the revenues obtained are:

$$Selling\ price = 5\ {}^{c€}/_{kWh}$$

With the irradiation data from Rome and considering that a 240W PV panel is installed in every locker the energy produced by the solar panels and the extra energy needed is:

P_{nom} PV (W)	240	**ROME**							
P_{real} PV (W)	192								
Month	**Days**	**Wh/day m²**	**Peak Solar Hours**	**E_{prod} (Wh/day)**	**E_{prod} (Wh/month)**	**E_{extra} (Wh/day)**	**E_{extra} (Wh/month)**	**E_{needed} (Wh/day)**	**E_{needed} (Wh/month)**
January	31	1800	1,8	345,6	10713,6	0	0	104,4	3236,4
February	28	2810	2,81	539,52	15106,56	89,52	2506,56	0	0
March	31	4140	4,14	794,88	24641,28	344,88	10691,28	0	0
April	30	5310	5,31	1019,52	30585,6	569,52	17085,6	0	0
May	31	6540	6,54	1255,68	38926,08	805,68	24976,08	0	0
June	30	7480	7,48	1436,16	43084,8	986,16	29584,8	0	0
July	31	7750	7,75	1488	46128	1038	32178	0	0
August	31	6720	6,72	1290,24	39997,44	840,24	26047,44	0	0
September	30	4900	4,9	940,8	28224	490,8	14724	0	0
October	31	3400	3,4	652,8	20236,8	202,8	6286,8	0	0
November	30	2100	2,1	403,2	12096	0	0	46,8	1404
December	31	1630	1,63	312,96	9701,76	0	0	137,04	4248,24
TOTAL	365	54580	54,58		319441,92		164080,56		8888,64

Table 36 Energy produced in 1 year in Rome

The cost of the energy needed for the months with less sun would be:

Country	Power (kW)	Price of power (€/kW)	Energy a year (kWh)	Consumption price (€/kWh)	Modules	Total Power (kW)	Total energy a year (kWh)	Cost per module (€)	Total yearly cost (€)
Spain	0,1	38,04	8,88864	0,1010	14	1,4	124,44096	4,70	65,83
Italy		23,00		0,0829				3,04	42,52

Table 37 Cost of energy needed in months with less sun

For a 14-module MOD-Hub, and considering the average price of electricity in Spain and Italy, the incomes from selling the extra energy are:

Energy costs (€)	Energy (kWh)	Selling price (c€/kWh)	Revenues 1 module (€)	Modules	Total revenues (€)
65,83	164,08056	5,37	8,81	14	123,36

Table 38 Revenues from sold energy

Considering an investment needed for each module of 500€, the cost comparison between a solar installation and a regular installation connected to the grid and the breakeven point is:

Inst.	Investment Needed (€)	Cost of energy and maintenance (€/year)	Taxes (€/year)	Revenues electricity (€/year)	Cash Flow (€/year)	Breakeven (years)
Solar	7000€	65,83	13	123,36	+45,35	154,37
Grid	-	285,5	-	-	-285,5	-

Table 39 Profitability comparison PV vs only-grid installation high investment

If a collective installation for a number of modules is made, the equipment would be optimised, and costs reduced. For example, if for every 14 lockers 3000€ are invested in equipment (14 solar panels + ~1500€ equipment), the results are:

Inst.	Investment Needed (€)	Cost of energy and maintenance (€/year)	Taxes (€/year)	Revenues electricity (€/year)	Cash Flow (€/year)	Breakeven (years)
Solar	3000€	65,83	13	114,86	+45,35	26,12
Grid	-	285,5	-	-	-285,5	-

Table 40 Profitability comparison PV vs only-grid installation low investment

These results are not considering the replacement of batteries and maintenance. The taxes analysis is based on regulation in Spain. In Italy the taxation for solar energy is lower.

The accumulated costs of having a grid system and a PV system for n years are

$$C_{GRID} = -c_e \cdot n$$

$$C_{PV} = -I + p_e \cdot n$$

p_e – profits for energy $\left(€/_{year}\right)$

c_e – cost of energy $\left(€/_{year}\right)$

n – years

I – Investment (€)

The point where the accumulated costs equal is:

$$n = \frac{I}{(c_e + p_e)} = \mathbf{18{,}03\ years}$$

6.12 CONCLUSIONS

From the analysis made a few conclusions can be extracted:

- To be able to maintain a total autonomy from the grid during all the year, very high-power panels would have to be installed. However, except during the months of December and January, the rest of the months have much lower requirements.
- Available equipment in the market is mainly aimed for higher power applications, this causes the cost per unit to be higher because there is no option but to oversize equipment.
- For permanent MOD-Hubs a shared installation to supply power should be considered. This would mean lower total costs and equipment optimization.

- Integrating a solar PV system adds value to the modules to solve the dependency from the grid in certain conditions and as a source of cleaner energy. In contrast, economically it is worthier to have a grid connected system or a shared PV installation by various modules.

CHAPTER 7. TESTS & FINAL RESULTS

7.1 INTRODUCTION

A number of tests have been carried during the whole development process to check the steps carried. These tests were focused in the control and communications systems. For the tests several functions have been programmed in a script for replicability.

7.2 GENERAL TESTS

The first tests carried to the boards where about general aspects such as visual inspection of the components, comparison of the manufactured boards with the CAD files and powering the boards to check for short-circuits. The tests for the control and communications system where divided into the different circuits, in order to test each one of the functionalities of the boards.

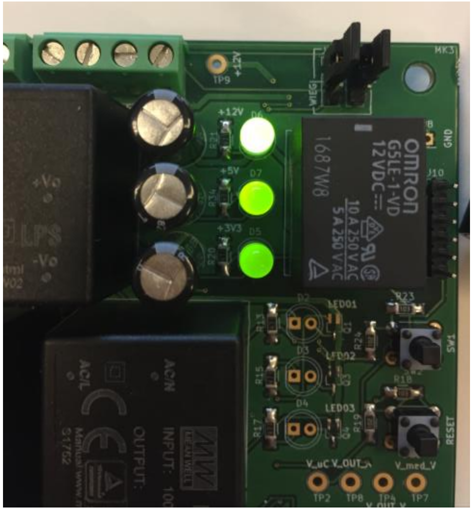


Figure 88 Power LEDs in the control board

7.3 CONTROL & COMMUNICATION SYSTEM TESTS

7.3.1 MCU DIGITAL I/OS TEST

To check the correct functioning of the digital inputs and outputs the LEDs and the switch were used. A program was used to configure the pins and then a flank detector in the switch would change the state of the corresponding pin of the LEDs. Through this test it was detected in the V0.1 of the control board that the MOSFET transistor used were not suitable, so for V1.0 they were changes into BJT technology transistors.

7.3.2 COMMUNICATIONS INTERFACE

To test the communications, a universal serial communications interface board was used: the Bus Pirate v3.6 [51], a low-cost board that helps communication debugging by providing a configurable communications interface with the computer. With this board and a communications debugger software in the computer, it was used the Cool Term freeware [52] the communications were tested. During these tests it was found out that the maximum transmission speed was 37800bps (bits per second), above that level messages would get corrupted in the transmission lines. This is probably due to parasite impedances that appear in the circuit routes because of length and layout.

Figure 89 Bus Pirate v3.6a

For the tests every time the switch was pressed, it would send the string of characters "PING" through the UART and the objective was to see it in the computer.

7.3.3 ACCESS CONTROL

For the access control there three different tests were carried: for the door sensor, the door opening and the RFID reader.

- Door sensor. To test the door sensor, it was set that whenever the door was closed a LED would be turned on.
- Door opening. The door opening was tested using the switch. Once the switch was pressed, the relay would be active for 5 seconds. With this test it was detected that as with the LEDs the MOSFET transistor used were not suitable, so for the V1.0 the transistor was changed for a BJT.
- RFID reader. Once the UARTs were tested, the RFID would read an IDtag, send the complete reading through one UART and then process it to send the relevant part through the other UART.

7.3.4 BATTERY MONITORING

For the battery monitoring the objective was to test the sensibility of the sensors and the functioning of the ADC. This was done using two different batteries with different SoC: one of them fully charged (according to the own bike metering) and another with low battery.

The measures for the tests were taken with a digital multimeter in the existing test points of the circuit and the results were stable measures with variation proportional to the SoC. The battery fully charged was draining very low current and nearly the float value of voltage, while the low battery was draining stable current and less voltage.

7.4 FINAL RESULTS

As a result, the following objectives of the project have been accomplished:

- The design paradigms have been established to serve as a guideline for the development of the product. They have been placed in a framework to have a common criterion when making decisions.

- The system architecture has been designed within the framework previously described and considering the design principles. This architecture contains the main structure of the functionalities and the relation between subsystems.
- A general engineering design has been made of the main subsystems of the product: the mechanical design with the shape and dimensions analysis, the electrical requirements and the applying normative; the control system with the components, functionalities ang programming workflows; and the desired IT functionalities for the managing platform.
- A 3D model of the product with its different possible layouts has been developed.
- Two printed circuit boards for the control of the different modules and the communications with the IT platform have been developed. These circuits have been defined to have reusable sub-circuits for specific functions which can be isolated and taken advantage for other applications.
- A full set of test procedures for the developed boards have been programmed and the structure of the code for further developments has been established.
- Main code libraries for managing different tasks have been programmed and systematised for further developments.
- A study on the energy needs of the product, the alternatives for the its energy management and a study of pheasability of a clean energy system powered by solar energy has been analysed.
- Very specific and detailed design specifications have been elaborated as a compilation of all of the concept improvements and designs of the product.

CHAPTER 8. CONCLUSIONS & FUTURE DEVELOPMENTS

8.1 CONCLUSIONS

At the end of this project the following aspects of product have been developed successfully.

- A design that ensures adaptability to different geometries, allowing to adapt to the conditions of any location to be deployed in. This design is valid for both circular and linear configurations of the MOD-Hub using the minimum space possible to avoid interfering with the city life.
- A control system capable of managing the functioning and main functions of each one of the modules at a low cost. This technology uses the latest improvements in IoT to provide total connectivity to a remote cloud server which will allow the management to know at every moment the status of the system and its performance. With this information the service will be adapted to the user needs in real time satisfying the demand where it is most needed.
- A energy management system has been proposed and analysed in order to make the product energetically independent to use more sustainable power sources and reduce the impact in the environment and enable to place the product in both temporal locations which don't want to invest into the infrastructure needed, and permanent locations with low carbon footprint.

This system will be major innovation in the market where it competes as it offers a number of advantages that pose it at the front of the existing products.

- It offers flexibility and adaptability to respond in real-time to the demand offering security for the user and the equipment.
- Through connectivity, the management can know at any time the status and the performance of the system, reducing error solving and service interruptions.

- All of this at a low-price compared to competitors by using a mix of off-shelf technology and custom-made equipment which benefits from scale economies.

8.2 FUTURE DEVELOPMENTS

Nevertheless, the product it is still not finished, and some aspects need fine tune and development for the future in order to have a full market deployment.

- The IT platform must be implemented and integrated with the control and communication system. This comprehends the cloud server and the mobile app for users. This way, functionality will be enhanced to provide with a better user experience. Once these services are developed, the control system firmware will have to be adapted accordingly to work best with them.
- Detailed plans and documentation of the mechanical design must be made, this includes the definition of the manufacturing process needed and, layout of the elements inside of the modules or the cabling.

As a different approach it has recently came up integrating technology from different industries. In this case, it has been evaluated and discussed the adaptability of parcel delivery lockers, which in essence is a similar service, but with different object sizes. Making use of this existing technologies could drop the costs even more than it was thought possible with custom made equipment.

Table 41 Smart Locker for parcels

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DOCUMENT II

BUDGET

Index

Tables Index

CHAPTER 1. BILLS OF QUANTITIES

In this chapter there are gathered the quantity of the components, equipment and human resources that have been committed during the project.

1.1 MAIN COMPONENTS

Components	Quantity (units)
Metal locker custom made	1
Screws and Accessories	10
Electric strike door lock	1
RFID reader serial interface	1
Door lock & slider	1

Table 1 Main components BoQ

1.2 CONTROL SYSTEM PRINTED CIRCUIT BOARD

Components	Quantity (units)
Control PCB	1
SMD Capacitors 0.1uF 20% 805	7
SMD Capacitors 10uF 20% 805	1
SMD Capacitors 4.7nF 5% 805	3
THT Capacitors 470uF 20% 805	3
TVS Diodes 7V 600W	1
5mm LED diode	6
Screw terminal 2poles	4
Screw terminal 4poles	2
Pin Header Straight 1x01 Pitch2.54mm	2
Pin Header Straight 1x02 Pitch2.54mm	6
Pin Header Straight 1x03 Pitch2.54mm	2
Pin Header Straight 1x06 Pitch2.54mm	1
Jumper pitch 1x02 Pitch2.54mm	3
Relay OMRON-G5LE-1-DC12	2
Current transducer LEM_HO_8-NP_SP33	1
MeanWell ACDC Converter 5W 3.3V	1
MeanWell ACDC Converter 20W 12V	1
MeanWell ACDC Converter 5W 5V	1

Components	**Quantity (units)**
THT N Channel BJT Transistor BC237	5
SMD N-Channel MOSFET Transistor BSS138L	5
SMD Resistor 10k 5% 1206	14
SMD Resistor 100k 5% 1206	6
SMD Resistor 15k 5% 1206	2
SMD Resistor 68 5% 1206	4
SMD Resistor 375 1% 1206	1
SMD Resistor 470 5% 1206	1
SMD Resistor 1M 5% 1206	2
SMD Resistor 120k 5% 1206	1
SMD Resistor 1k 5% 1206	2
SMD Resistor 27k 5% 1206	1
SMD Resistor 2.7k 1% 1206	4
SMD Resistor 6.8k 5% 1206	2
SMD Resistor 10 5% 1206	2
SMD Resistor 120 5% 1206	1
Tactile Switch THT 6mm	2
Serial to RS485 Transceiver SN65HVD12DR	1
Op. Amp. LMV722ID	2
Microcontroller Unit PIC32MX174F256B	1
Magnetic proximity sensor	1
Actuator for magnetic proximity sensor	1

Table 2 Control printed circuit board components BoQ

1.3 COMMUNICATIONS PRINTED CIRCUIT BOARD

Components	**Quantity (units)**
Communications PCB	1
SMD Capacitors 0.1uF 20% 805	5
THT Capacitors 470uF 20% 805	1
SMD Capacitors 10uF 20% 805	1
5mm LED diode	3
TVS Diodes 7V 600W	1
Screw terminal 2poles	2
Pin Header Straight 1x08 Pitch2.54mm	2
Pin Header Straight 1x06 Pitch2.54mm	1
Pin Header Straight 1x01 Pitch2.54mm	1
Pin Header Straight 1x02 Pitch2.54mm	1
MeanWell ACDC Converter 5W 3.3V	1

Components	Quantity (units)
THT N Channel BJT Transistor BC237	2
SMD Resistor 10k 5% 1206	4
SMD Resistor 120 5% 1206	1
SMD Resistor 375 1% 1206	2
SMD Resistor 2.7k 1% 1206	2
SMD Resistor 68 5% 1206	2
SMD Resistor 1k 5% 1206	2
SMD Resistor 10 5% 1206	2
SMD Resistor 47 5% 1206	1
Tactile Switch THT 6mm	2
Serial to RS485 Transceiver SN65HVD12DR	1
Microcontroller Unit PIC32MX174F256B	1
GSM module Mikroe GSM2	1
GMS Antenna Mikroe SMA RA Connector	1

Table 3 Communications board components BoQ

1.4 SOFTWARE

Program	Hours project	Hours a year
KiCad	250	400
MPLAB X IDE v4.15	150	400
CoolTerm	40	50
Microsoft Office	250	1000
Solid Edge ST9	40	100

Table 4 Software BoQ

1.5 TOOLS AND EQUIPMENT

Equipment	Quantity (units)	Hours project	Hours a year
Computer	1	750	1800
Microchip PICKIT3	1	150	250
Power Supply	1	200	400
Oscilloscope	1	50	100
Multimeter	1	80	150
Tin solder	1	10	40
Desolder	1	2	5
Tools	1	50	120

Table 5 Tools and equipment BoQ

1.6 MANPOWER

Task	**Hours**
General Design	300
Programming	100
PCB Design	280
Testing	100
Mounting	20
Elaboration of documentation	200

Table 6 Manpower BoQ

CHAPTER 2. UNITARY PRICES

In this chapter all the unitary prices of the different components, equipment and hour prices are shown.

1.7 MAIN COMPONENTS

Components	Price (€/unit)
Metal locker custom made	800.00
Screws and Accessories	5.00
Electric strike door lock	30.00
RFID reader serial interface	30.00
Door lock & slider	20.00

Table 7 Unitary prices of the main components

1.8 CONTROL SYSTEM PRINTED CIRCUIT BOARD

Components	Price (€/unit)
Control PCB	42.50
SMD Capacitors 0.1uF 20% 805	0.08
SMD Capacitors 10uF 20% 805	0.16
SMD Capacitors 4.7nF 5% 805	0.08
THT Capacitors 470uF 20% 805	0.50
TVS Diodes 7V 600W	1.40
5mm LED diode	0.70
Screw terminal 2poles	0.86
Screw terminal 4poles	1.73
Pin Header Straight 1x01 Pitch2.54mm	0.05
Pin Header Straight 1x02 Pitch2.54mm	0.10
Pin Header Straight 1x03 Pitch2.54mm	0.15
Pin Header Straight 1x06 Pitch2.54mm	0.20
Jumper pitch 1x02 Pitch2.54mm	0.05
Relay OMRON-G5LE-1-DC12	1.00
Current transducer LEM_HO_8-NP_SP33	7.55
MeanWell ACDC Converter 5W 3.3V	6.74
MeanWell ACDC Converter 20W 12V	9.86
MeanWell ACDC Converter 5W 5V	7.42
THT N Channel BJT Transistor BC237	0.44
SMD N-Channel MOSFET Transistor BSS138L	0.18

Components	Price (€/unit)
SMD Resistor 10k 5% 1206	0.01
SMD Resistor 100k 5% 1206	0.03
SMD Resistor 15k 5% 1206	0.02
SMD Resistor 68 5% 1206	0.03
SMD Resistor 375 1% 1206	0.03
SMD Resistor 470 5% 1206	0.01
SMD Resistor 1M 5% 1206	0.04
SMD Resistor 120k 5% 1206	0.02
SMD Resistor 1k 5% 1206	0.03
SMD Resistor 27k 5% 1206	0.02
SMD Resistor 2.7k 1% 1206	0.02
SMD Resistor 6.8k 5% 1206	0.05
SMD Resistor 10 5% 1206	0.06
SMD Resistor 120 5% 1206	0.03
Tactile Switch THT 6mm	0.23
Serial to RS485 Transceiver SN65HVD12DR	2.49
Op. Amp. LMV722ID	1.11
Microcontroller Unit PIC32MX174F256B	4.03
Magnetic proximity sensor	2.19
Actuator for magnetic proximity sensor	3.26

Table 8 Control system printed circuit board unitary prices

1.9 COMMUNICATIONS PRINTED CIRCUIT BOARD

Components	Price (€/unit)
Communications PCB	40.00
SMD Capacitors 0.1uF 20% 805	0.08
THT Capacitors 470uF 20% 805	0.50
SMD Capacitors 10uF 20% 805	0.16
5mm LED diode	0.70
TVS Diodes 7V 600W	1.40
Screw terminal 2poles	0.86
Pin Header Straight 1x08 Pitch2.54mm	0.22
Pin Header Straight 1x06 Pitch2.54mm	0.20
Pin Header Straight 1x01 Pitch2.54mm	0.05
Pin Header Straight 1x02 Pitch2.54mm	0.10
MeanWell ACDC Converter 5W 3.3V	6.74
THT N Channel BJT Transistor BC237	0.44
SMD Resistor 10k 5% 1206	0.01
SMD Resistor 120 5% 1206	0.03
SMD Resistor 375 1% 1206	0.03
SMD Resistor 2.7k 1% 1206	0.02

Components	Price (€/unit)
SMD Resistor 68 5% 1206	0.03
SMD Resistor 1k 5% 1206	0.03
SMD Resistor 10 5% 1206	0.06
SMD Resistor 47 5% 1206	0.02
Tactile Switch THT 6mm	0.23
Serial to RS485 Transceiver SN65HVD12DR	2.49
Microcontroller Unit PIC32MX174F256B	4.03
GSM module Mikroe GSM2	36.80
GMS Antenna Mikroe SMA RA Connector	5.66

Table 9 Communications printed circuit board unitary prices

1.10 SOFTWARE

Program	Price (€/year)
KiCad	Freeware
MPLAB X IDE v4.15	Freeware
CoolTerm	Freeware
Microsoft Office	101.00
Solid Edge ST9	160.00

Table 10 Software unitary prices

1.11 TOOLS AND EQUIPMENT

Equipment	Price (€)
Computer	1,600.00
Microchip PICKIT3	40.00
Power Supply	30.00
Oscilloscope	60.00
Multimeter	40.00
Tin solder	30.00
Desolder	15.00
Tools	100.00

Table 11 Tools and equipment unitary prices

1.12 MANPOWER

Task	Cost (€/h)
General Design	35.00
Programming	30.00
PCB Design	40.00
Testing	45.00
Mounting	15.00
Elaboration of documentation	40.00

Table 12 Manpower unitary prices

CHAPTER 3. PARTIAL SUMS

In this chapter the partial sums of every category are calculated from the unitary costs and bills of quantity.

1.13 MAIN COMPONENTS

Components	Quantity (units)	Price (€/unit)	Cost (€)
Metal locker custom made	1	800.00	800.00
Screws and Accessories	10	5.00	50.00
Electric strike door lock	1	30.00	30.00
RFID reader serial interface	1	30.00	30.00
Door lock & slider	1	20.00	20.00
TOTAL			**930.00**

Table 13 Main components partial sum

1.14 CONTROL SYSTEM PRINTED CIRCUIT BOARD

Components	Quantity (units)	Price (€/unit)	Cost (€)
Control PCB	1	42.50	42.50
SMD Capacitors 0.1uF 20% 805	7	0.08	0.57
SMD Capacitors 10uF 20% 805	1	0.16	0.16
SMD Capacitors 4.7nF 5% 805	3	0.08	0.25
THT Capacitors 470uF 20% 805	3	0.50	1.50
TVS Diodes 7V 600W	1	1.40	1.40
5mm LED diode	6	0.70	4.20
Screw terminal 2poles	4	0.86	3.44
Screw terminal 4poles	2	1.73	3.46
Pin Header Straight 1x01 Pitch2.54mm	2	0.05	0.10
Pin Header Straight 1x02 Pitch2.54mm	6	0.10	0.60
Pin Header Straight 1x03 Pitch2.54mm	2	0.15	0.30
Pin Header Straight 1x06 Pitch2.54mm	1	0.20	0.20
Jumper pitch 1x02 Pitch2.54mm	3	0.05	0.15
Relay OMRON-G5LE-1-DC12	2	1.00	2.00
Current transducer LEM_HO_8-NP_SP33	1	7.55	7.55
MeanWell ACDC Converter 5W 3.3V	1	6.74	6.74
MeanWell ACDC Converter 20W 12V	1	9.86	9.86
MeanWell ACDC Converter 5W 5V	1	7.42	7.42
THT N Channel BJT Transistor BC237	5	0.44	2.20

Components	Quantity (units)	Price (€/unit)	Cost (€)
SMD N-Channel MOSFET Transistor BSS138L	5	0.18	0.90
SMD Resistor 10k 5% 1206	14	0.01	0.18
SMD Resistor 100k 5% 1206	6	0.03	0.19
SMD Resistor 15k 5% 1206	2	0.02	0.04
SMD Resistor 68 5% 1206	4	0.03	0.12
SMD Resistor 375 1% 1206	1	0.03	0.03
SMD Resistor 470 5% 1206	1	0.01	0.01
SMD Resistor 1M 5% 1206	2	0.04	0.07
SMD Resistor 120k 5% 1206	1	0.02	0.02
SMD Resistor 1k 5% 1206	2	0.03	0.06
SMD Resistor 27k 5% 1206	1	0.02	0.02
SMD Resistor 2.7k 1% 1206	4	0.02	0.08
SMD Resistor 6.8k 5% 1206	2	0.05	0.09
SMD Resistor 10 5% 1206	2	0.06	0.13
SMD Resistor 120 5% 1206	1	0.03	0.03
Tactile Switch THT 6mm	2	0.23	0.46
Serial to RS485 Transceiver SN65HVD12DR	1	2.49	2.49
Op. Amp. LMV722ID	2	1.11	2.22
Microcontroller Unit PIC32MX174F256B	1	4.03	4.03
Magnetic proximity sensor	1	2.19	2.19
Actuator for magnetic proximity sensor	1	3.26	3.26
TOTAL			**111.22**

Table 14 Control system printed circuit board partial sum

1.15 COMMUNICATIONS PRINTED CIRCUIT BOARD

Components	Quantity (units)	Price (€/unit)	Cost (€)
Communications PCB	1	40.00	40.00
SMD Capacitors 0.1uF 20% 805	5	0.08	0.41
THT Capacitors 470uF 20% 805	1	0.50	0.50
SMD Capacitors 10uF 20% 805	1	0.16	0.16
5mm LED diode	3	0.70	2.10
TVS Diodes 7V 600W	1	1.40	1.40
Screw terminal 2poles	2	0.86	1.72
Pin Header Straight 1x08 Pitch2.54mm	2	0.22	0.44
Pin Header Straight 1x06 Pitch2.54mm	1	0.20	0.20
Pin Header Straight 1x01 Pitch2.54mm	1	0.05	0.05
Pin Header Straight 1x02 Pitch2.54mm	1	0.10	0.10
MeanWell ACDC Converter 5W 3.3V	1	6.74	6.74
THT N Channel BJT Transistor BC237	2	0.44	0.88
SMD Resistor 10k 5% 1206	4	0.01	0.05
SMD Resistor 120 5% 1206	1	0.03	0.03

Components	Quantity (units)	Price (€/unit)	Cost (€)
SMD Resistor 375 1% 1206	2	0.03	0.07
SMD Resistor 2.7k 1% 1206	2	0.02	0.04
SMD Resistor 68 5% 1206	2	0.03	0.06
SMD Resistor 1k 5% 1206	2	0.03	0.06
SMD Resistor 10 5% 1206	2	0.06	0.13
SMD Resistor 47 5% 1206	1	0.02	0.02
Tactile Switch THT 6mm	2	0.23	0.46
Serial to RS485 Transceiver SN65HVD12DR	1	2.49	2.49
Microcontroller Unit PIC32MX174F256B	1	4.03	4.03
GSM module Mikroe GSM2	1	36.80	36.80
GMS Antenna Mikroe SMA RA Connector	1	5.66	5.66
TOTAL			**104.59**

Table 15 Communications printed circuit board partial sum

1.16 SOFTWARE

Program	Price (€/year)	Hours project	Hours year	Cost (€)
KiCad	Freeware	250	400	-
MPLAB X IDE v4.15	Freeware	150	400	-
CoolTerm	Freeware	40	50	-
Microsoft Office	101.00	250	1000	25.25
Solid Edge ST9	160.00	40	100	64.00
TOTAL				**89.25**

Table 16 Software partial sum

1.17 TOOLS AND EQUIPMENT

For the tools and equipment, it has been considered a 4-year depreciation period with a proportional cost from the relation between project usage and yearly usage.

Equipment	Quantity (units)	Price (€)	Hours project	Hours year	Yearly amortization	Cost (€)
Computer	1	1,600.00	750	1800	25%	2,666.67
Microchip PICKIT3	1	40.00	150	250		96.00
Power Supply	1	30.00	200	400		60.00
Oscilloscope	1	60.00	50	100		120.00
Multimeter	1	40.00	80	150		85.33
Tin solder	1	30.00	10	40		30.00
Desolder	1	15.00	2	5		24.00
Tools	1	100.00	50	120		166.67
TOTAL						**3,248.67**

Table 17 Tools and equipment partial sum

1.18 MANPOWER

Task	Hours	Cost (€/h)	Total Cost (€)
General Design	300	35.00	10,500.00
Programming	100	30.00	3,000.00
PCB Design	280	40.00	11,200.00
Testing	100	45.00	4,500.00
Mounting	20	15.00	300.00
Elaboration of documentation	200	40.00	8,000.00
TOTAL	**1000**		**37,500.00**

Table 18 Manpower partial sum

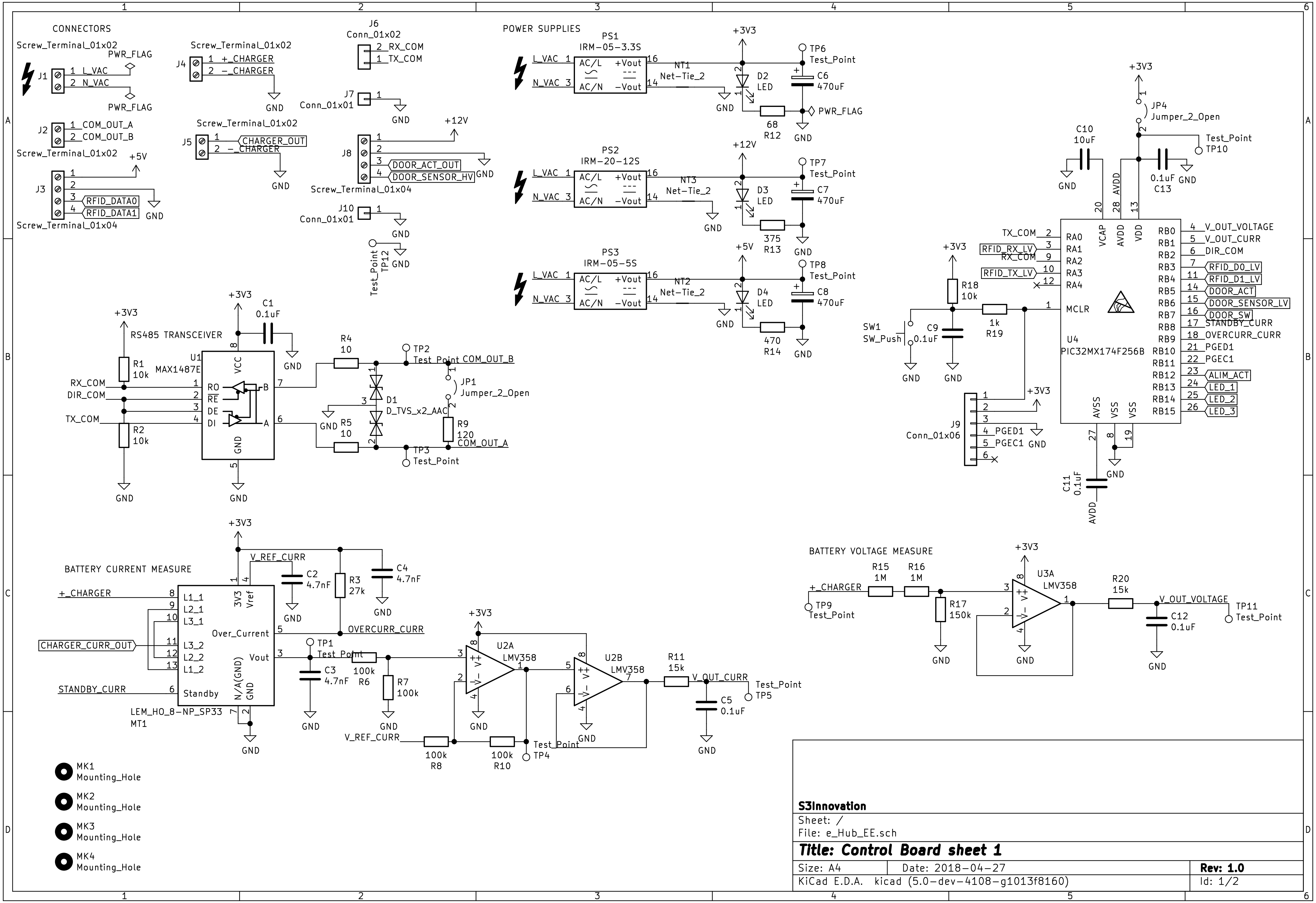
CHAPTER 4. GENERAL BUDGET

From the partial sums the general budget is as follows:

Budget heading	**Cost (€)**
Main Components	930.00
Control system printed circuit board	111.22
Communications printed circuit board	104.59
Software	89.25
Tools and Equipment	3,248.67
Manpower	37,500.00
TOTAL	**41,983.72**

Table 19 General budget

ANNEX A: SCHEMATICS


CONNECTORS
Screw_Terminal_01x02
PWR_FLAG
J1
1 L_VAC
2 N_VAC
J2
1 COM_OUT_A
2 COM_OUT_B
+5V
J3
1
2
3 RFID_DATA0
4 RFID_DATA1
Screw_Terminal_01x04
J4
1 +_CHARGER
2 -_CHARGER
J5
1 CHARGER_OUT
2 -_CHARGER
J6
Conn_01x02
2 RX_COM
1 TX_COM
J7
Conn_01x01
J8
+12V
3 DOOR_ACT_OUT
4 DOOR_SENSOR_HV
J10
Test_Point
TP12
GND
POWER SUPPLIES
PS1
IRM-05-3.3S
PS2
IRM-20-12S
PS3
IRM-05-5S
L_VAC
N_VAC
AC/L
AC/N
+Vout
-Vout
+3V3
NT1
NT2
NT3
Net-Tie_2
D2
D3
D4
LED
TP6
TP7
TP8
C6
C7
C8
470uF
68
R12
375
R13
470
R14
PWR_FLAG
RS485 TRANSCEIVER
U1
MAX1487E
RO
RE
DE
DI
VCC
R1
10k
R2
10k
RX_COM
DIR_COM
TX_COM
C1
0.1uF
R4
10
R5
10
TP2
TP3
COM_OUT_B
COM_OUT_A
JP1
Jumper_2_Open
D1
D_TVS_x2_AAC
R9
120
U4
PIC32MX174F256B
RA0
RA1
RA2
RA3
RA4
MCLR
VCAP
AVDD
VDD
AVSS
VSS
RB0 V_OUT_VOLTAGE
RB1 V_OUT_CURR
RB2 DIR_COM
RB3 RFID_D0_LV
RB4 RFID_D1_LV
RB5 DOOR_ACT
RB6 DOOR_SENSOR_LV
RB7 DOOR_SW
RB8 STANDBY_CURR
RB9 OVERCURR_CURR
RB10 PGED1
RB11 PGEC1
RB12 ALIM_ACT
RB13 LED_1
RB14 LED_2
RB15 LED_3
RFID_RX_LV
RFID_TX_LV
C10
10uF
C13
0.1uF
JP4
Jumper_2_Open
TP10
R18
10k
R19
1k
SW1
SW_Push
C9
0.1uF
J9
Conn_01x06
PGED1
PGEC1
C11
0.1uF
BATTERY CURRENT MEASURE
+_CHARGER
CHARGER_CURR_OUT
STANDBY_CURR
L1_1
L2_1
L3_1
L3_2
L2_2
L1_2
Standby
3V3
Vref
Over_Current
Vout
N/A(GND)
LEM_HO_8-NP_SP33
MT1
V_REF_CURR
C2
4.7nF
R3
27k
C4
4.7nF
OVERCURR_CURR
TP1
C3
4.7nF
R6
100k
R7
100k
U2A
LMV358
U2B
LMV358
R8
100k
R10
100k
TP4
R11
15k
V_OUT_CURR
TP5
C5
0.1uF
BATTERY VOLTAGE MEASURE
R15
1M
R16
1M
R17
150k
TP9
U3A
LMV358
R20
15k
V_OUT_VOLTAGE
C12
0.1uF
TP11
MK1
MK2
MK3
MK4
Mounting_Hole
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Size: A4
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Rev: 1.0
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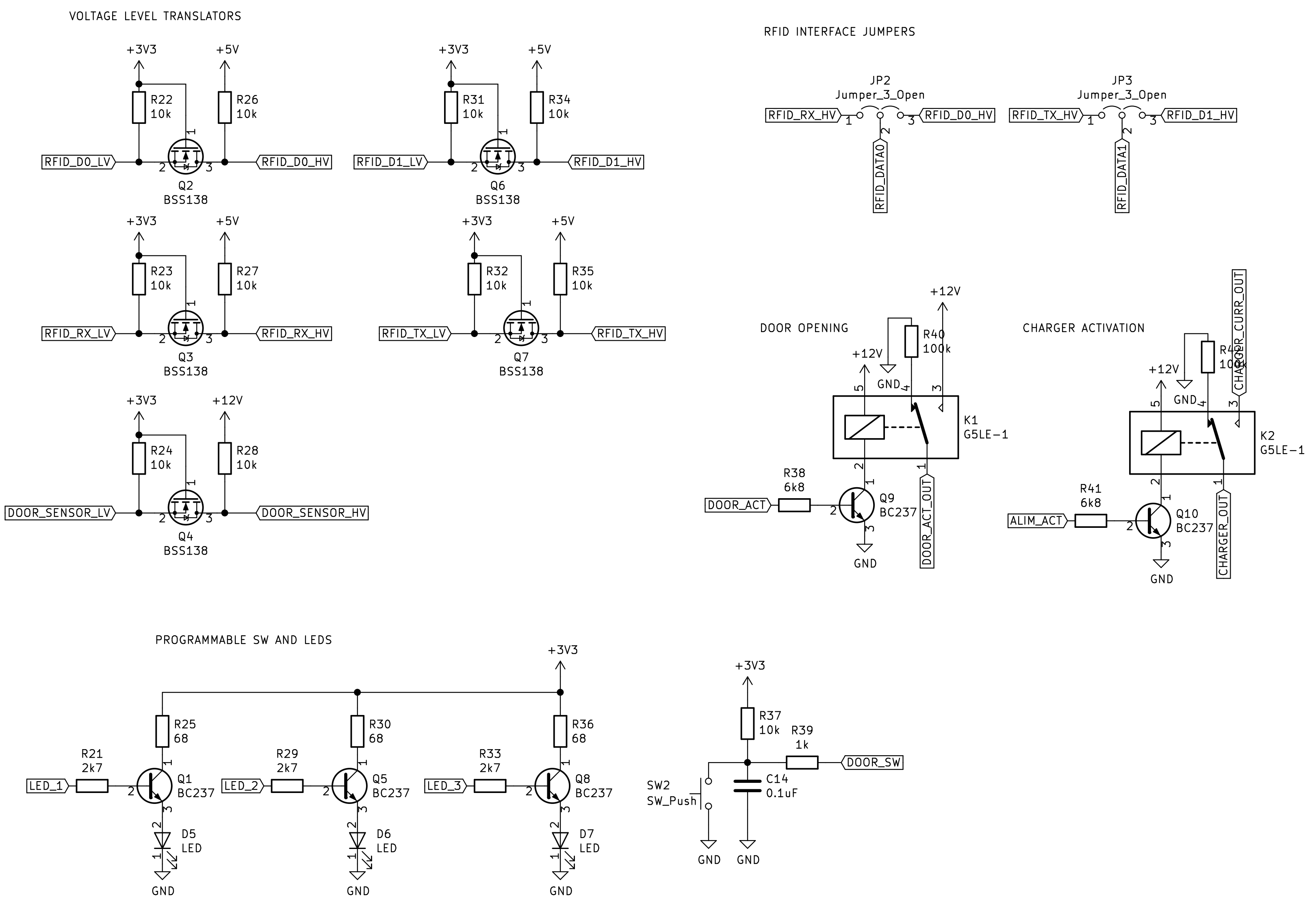

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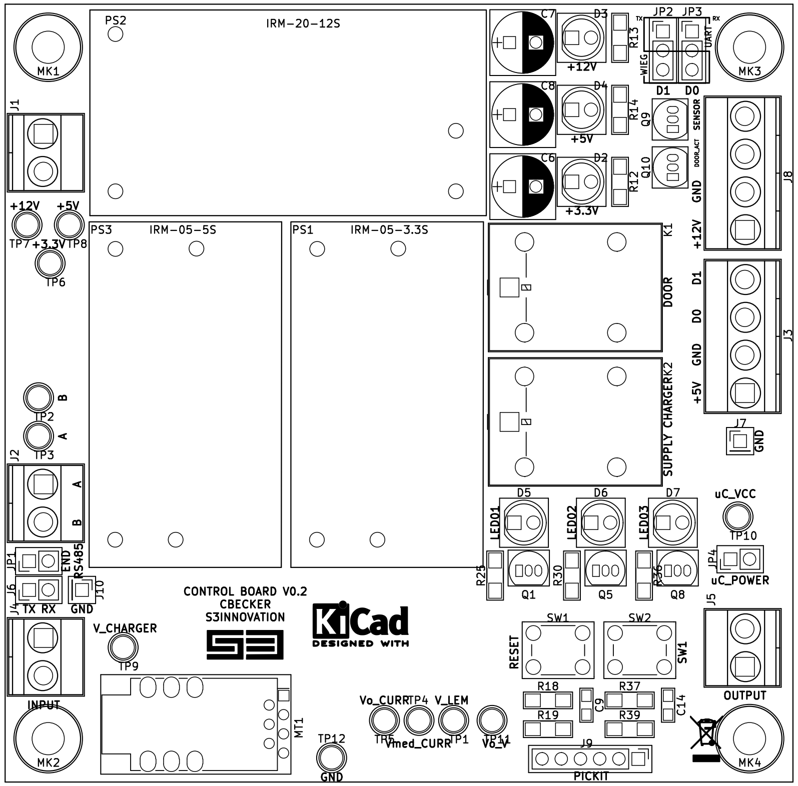

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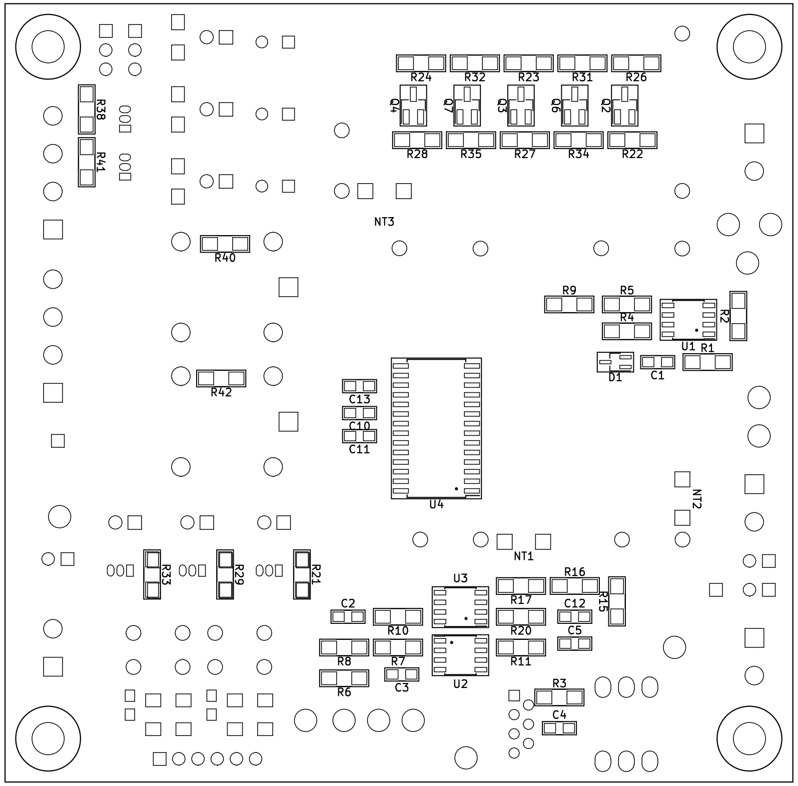

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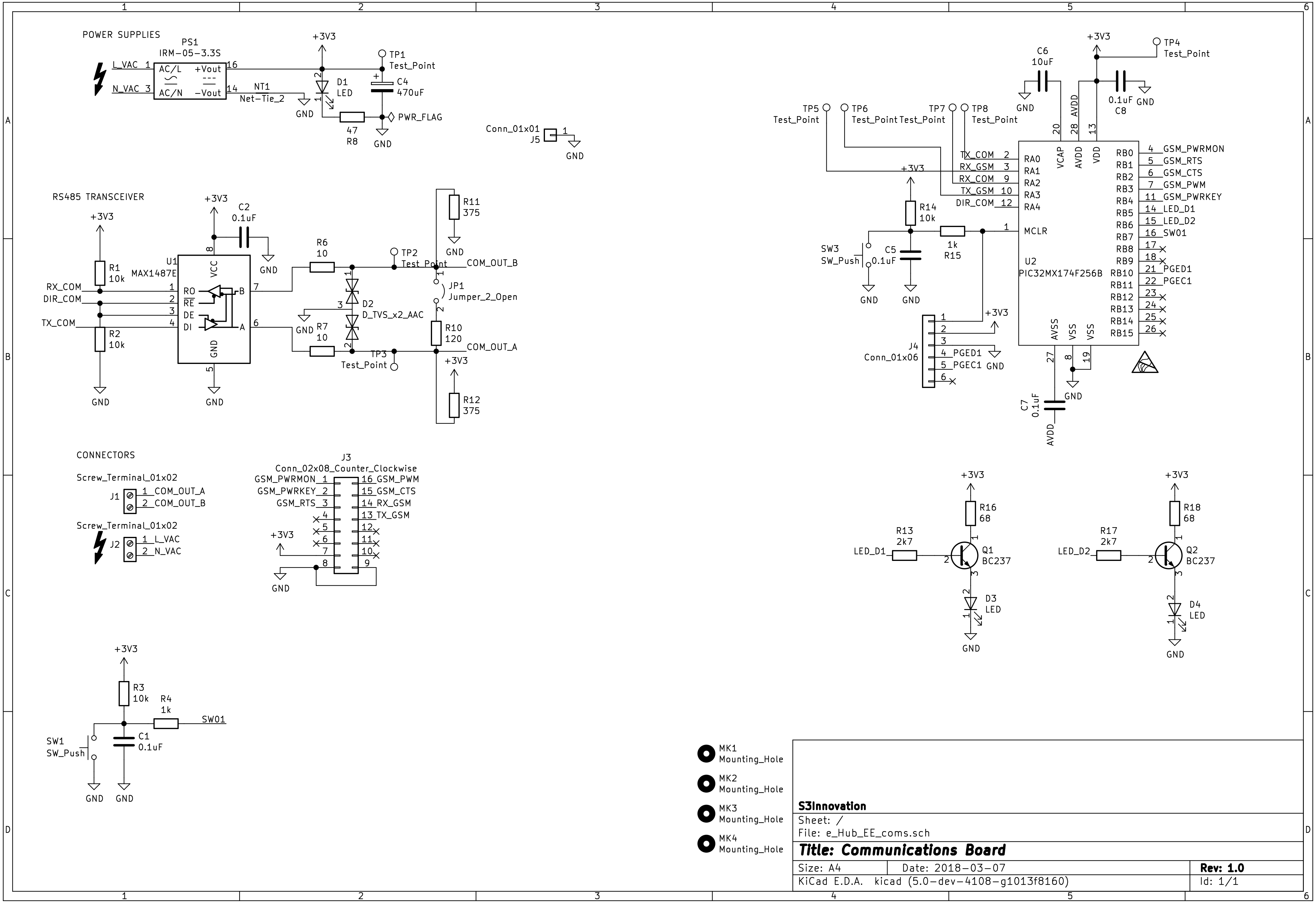
POWER SUPPLIES
PS1
IRM-05-3.3S
L_VAC 1 AC/L +Vout 16
N_VAC 3 AC/N -Vout 14
NT1
Net-Tie_2
GND
+3V3
D1
LED
TP1
Test_Point
C4
470uF
47
R8
PWR_FLAG
GND
Conn_01x01
J5
GND
RS485 TRANSCEIVER
+3V3
R1
10k
RX_COM
DIR_COM
TX_COM
R2
10k
GND
U1
MAX1487E
RO
RE
DE
DI
VCC
GND
B
A
+3V3
C2
0.1uF
GND
R6
10
R7
10
D2
D_TVS_x2_AAC
GND
TP2
Test_Point
TP3
Test_Point
COM_OUT_B
COM_OUT_A
JP1
Jumper_2_Open
R10
120
R11
375
R12
375
+3V3
GND
CONNECTORS
Screw_Terminal_01x02
J1
1 COM_OUT_A
2 COM_OUT_B
Screw_Terminal_01x02
J2
1 L_VAC
2 N_VAC
J3
Conn_02x08_Counter_Clockwise
GSM_PWRMON 1
GSM_PWRKEY 2
GSM_RTS 3
16 GSM_PWM
15 GSM_CTS
14 RX_GSM
13 TX_GSM
+3V3
GND
+3V3
R3
10k
R4
1k
SW01
SW1
SW_Push
C1
0.1uF
GND
GND
C6
10uF
+3V3
TP4
Test_Point
0.1uF
C8
GND
GND
TP5
Test_Point
TP6
Test_Point
TP7
Test_Point
TP8
Test_Point
TX_COM 2 RA0
RX_GSM 3 RA1
RX_COM 9 RA2
TX_GSM 10 RA3
DIR_COM 12 RA4
MCLR
VCAP
AVDD
VDD
U2
PIC32MX174F256B
RB0 4 GSM_PWRMON
RB1 5 GSM_RTS
RB2 6 GSM_CTS
RB3 7 GSM_PWM
RB4 11 GSM_PWRKEY
RB5 14 LED_D1
RB6 15 LED_D2
RB7 16 SW01
RB8 17
RB9 18
RB10 21 PGED1
RB11 22 PGEC1
RB12 23
RB13 24
RB14 25
RB15 26
AVSS
VSS
VSS
+3V3
R14
10k
1k
R15
SW3
SW_Push
C5
0.1uF
GND
GND
J4
Conn_01x06
+3V3
4 PGED1
5 PGEC1
GND
GND
C7
0.1uF
AVDD
+3V3
R16
68
R13
2k7
LED_D1
Q1
BC237
D3
LED
GND
+3V3
R18
68
R17
2k7
LED_D2
Q2
BC237
D4
LED
GND
MK1
Mounting_Hole
MK2
Mounting_Hole
MK3
Mounting_Hole
MK4
Mounting_Hole
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Rev: 1.0
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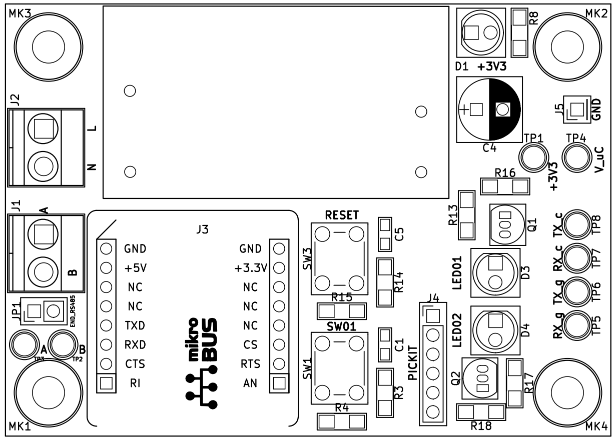

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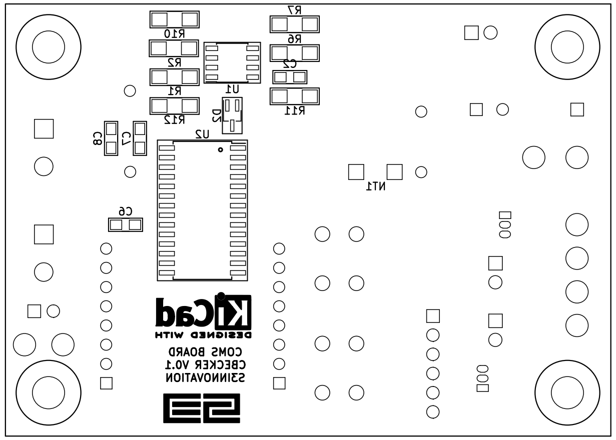

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ANNEX B: BILLS OF MATERIALS

Control Board

Ref	Value	Footprint	Manufacturer	Mnfr. Number	Units per PCB
C1, C5, C9, C11, C12, C13, C14	0.1uF	Capacitors_SMD:C_0805_HandSoldering	Vishay	VJ0805Y104MXXAC	7
C10	10uF	Capacitors_SMD:C_0805_HandSoldering	Taiyo Yuden	TMK212BBJ106MG-T	1
C2, C3, C4	4.7nF	Capacitors_SMD:C_0805_HandSoldering	Vishay	VJ0805Y472JXQPW1BC	3
C6, C7, C8	470uF	Capacitors_THT:CP_Radial_D8.0mm_P3.50mm	Panasonic	EEU-FM1E471L	3
D1	D TVSx2 AAC	TO_SOT_Packages_SMD:SOT-323_SC-70_Handsoldering	Bourns	CDSOT23-SM712	1
D2, D3, D4, D5, D6, D7	LED	LEDs:LED_D5.0mm			6
J1, J2, J4, J5	Screw Terminal 01x02	TerminalBlock_Phoenix:TerminalBlock_Phoenix_MKDS1.5-2pol	Phoenix Contact	1729128	4
J10	Conn_01x01	Pin_Headers:Pin_Header_Straight_1x01_Pitch2.54mm			1
J3, J8	Screw Terminal 01x04	TerminalBlock_Phoenix:TerminalBlock_Phoenix_MKDS1.5-4pol	Phoenix Contact	1729144	2
J6	Conn_01x02	Pin_Headers:Pin_Header_Straight_1x02_Pitch2.54mm			1

Ref	Value	Footprint	Manufacturer	Mnfr. Number	Units per PCB
J7	Conn_01x01	Pin_Headers:Pin_Header_Straight_1x01_Pitch2.54mm			1
J9	Conn_01x06	Pin_Headers:Pin_Header_Straight_1x06_Pitch2.54mm			1
JP1, JP4	Jumper 2 Open	Pin_Headers:Pin_Header_Straight_1x02_Pitch2.54mm			
JP2, JP3	Jumper 3 Open	Pin_Headers:Pin_Header_Straight_1x03_Pitch2.54mm			2
K1, K2	G5LE-1	Relays_THT:Relay_SPDT_OMRON-G5LE-1	Omron	G5LE-1-DC12	2
MK1, MK2, MK3, MK4	Mounting Hole	Mounting_Holes:MountingHole_4.3mm_M4			0
MT1	LEM HO 8-NP SP33	Hall-Effect_Transducers_LEM:LEM_HO-NP_SP33	LEM	HO 8-NP/SP3.3 1000	1
PS1	IRM-05-3.3	Converters_DCDC_ACDC:IRM-05	MeanWell	IRM-05-3.3	1
PS2	IRM-20-12	Converters_DCDC_ACDC:IRM-20	MeanWell	IRM-20-12	1
PS3	IRM-05-5	Converters_DCDC_ACDC:IRM-05	MeanWell	IRM-05-5	1
Q1, Q5, Q8, Q9, Q10	BC237	TO_SOT_Packages_THT:TO-92_Inline_Narrow_Oval	Central Semiconductor	BC237B	5
Q2, Q3, Q4, Q6, Q7	BSS138	TO_SOT_Packages_SMD:SOT-23_Handsoldering	ON Semiconductor/Fairchild	BSS138L	5
R1, R2, R18, R22, R23, R24, R26, R27, R28, R31, R32, R34, R35, R37	10k	Resistors_SMD:R_1206_HandSoldering	Bourns	CR1206-JW-103GLF	14

Ref	Value	Footprint	Manufacturer	Mnfr. Number	Units per PCB
R6, R7, R8, R10, R40, R42	100k	Resistors_SMD:R_1206_HandSoldering	Bourns	CR1206-JW-104GLF	6
R11, R20	15k	Resistors_SMD:R_1206_HandSoldering	Vishay	CRCW120615K0JNEA	2
R12, R25, R30, R36	68	Resistors_SMD:R_1206_HandSoldering	Panasonic	ERJ-8GEYJ680V	4
R13	375	Resistors_SMD:R_1206_HandSoldering	Bourns	CR1206-FX-3740ELF	1
R14	470	Resistors_SMD:R_1206_HandSoldering	Bourns	CR1206-JW-471GLF	1
R15, R16	1M	Resistors_SMD:R_1206_HandSoldering	Bourns	CR1206-JW-105GLF	2
R17	150k	Resistors_SMD:R_1206_HandSoldering	Vishay	CRCW1206120KJNEA	1
R19, R39	1k	Resistors_SMD:R_1206_HandSoldering	Bourns	CR1206-JW-102GLF	2
R3	27k	Resistors_SMD:R_1206_HandSoldering	Vishay	CRCW120627K0JNEB	1
R21, R29, R33	2k7	Resistors_SMD:R_1206_HandSoldering	Yageo	RC1206FR-072K7L	4
R38, R41	6k8	Resistors_SMD:R_1206_HandSoldering	Yageo	AC1206JR-076K8L	2
R4, R5	10	Resistors_SMD:R_1206_HandSoldering	Cree, Inc	CR1206-JW-100ELF	2
R9	120	Resistors_SMD:R_1206_HandSoldering	Bourns	CR1206-JW-121ELF	1
SW1, SW2	SW_Push	Buttons_Switches_THT:SW_PUSH_6mm	Schurter	1301.9309	2
U1	SN65HVD12DR	Housings_SOIC:SOIC-8_3.9x4.9mm_Pitch1.27mm	Texas Instrument	SN65HVD12DR	1
U2, U3	LMV722ID	Housings_SOIC:SOIC-8_3.9x4.9mm_Pitch1.27mm	Texas Instrument	LMV722ID	2
U4	PIC32MX174F256B	Housings_SOIC:SOIC-28W_7.5x17.9mm_Pitch1.27mm	Microchip	PIC32MX174F256B-I/SO	1
		Magnetic proximity sensor	Littlefuse	59040-1-T-02-F	1

Ref	**Value**	**Footprint**	**Manufacturer**	**Mnfr. Number**	**Units per PCB**
		Actuator for magnetic proximity sensor	Littlefuse	57040-000	1
		RFID card reader serial	Parallax	28140	1

Communications Board

Ref	**Value**	**Footprint**	**Manufacturer**	**Mnfr. Number**	**Units per PCB**
C1, C2, C5, C7, C8	0.1uF	Capacitors_SMD:C_0805_HandSoldering	Vishay	VJ0805Y104MXXAC	5
C4	470uF	Capacitors_THT:CP_Radial_D8.0mm_P3.50mm	Panasonic	EEU-FM1E471L	1
C6	10uF	Capacitors_SMD:C_0805_HandSoldering	Taiyo Yuden	TMK212BBJ106MG-T	1
D1, D3, D4	LED	LEDs:LED_D5.0mm			3
D2	D TVSx2 AAC	TO_SOT_Packages_SMD:SOT-323_SC-70_Handsoldering	Bourns	CDSOT23-SM712	1
J1, J2	Screw Terminal 01x02	TerminalBlock_Phoenix:TerminalBlock_Phoenix_MKDS1.5-2pol	-	-	2
J3	Conn 02x08 Counter Clockwise	CBecker:MikroBus_GSM	-	-	1
J4	Conn 01x06	Pin_Headers:Pin_Header_Straight_1x06_Pitch2.54mm	-	-	1
J5	Conn 01x01	Pin_Headers:Pin_Header_Straight_1x01_Pitch2.54mm	-	-	1

Ref	**Value**	**Footprint**	**Manufacturer**	**Mnfr. Number**	**Units per PCB**
JP1	Jumper 2 Open	Pin_Headers:Pin_Header_Straight_1x02_Pitch2.54mm	-	-	1
PS1	IRM-05-3.3S	Converters_DCDC_ACDC:IRM-05	IRM-05-3.3S	MeanWell	1
Q1, Q2	BC237	TO_SOT_Packages_THT:TO-92_Inline_Narrow_Oval	Central Semiconductor	BC237B	2
R1, R2, R3, R14	10k ohms	Resistors_SMD:R_1206_HandSoldering	Bourns	CR1206-JW-103GLF	4
R10	120 ohms	Resistors_SMD:R_1206_HandSoldering	Bourns	CR1206-JW-121ELF	1
R11, R12	375 ohms	Resistors_SMD:R_1206_HandSoldering	Bourns	CR1206-FX-3740ELF	2
R13, R17	2k7 ohms	Resistors_SMD:R_1206_HandSoldering	Yageo	RC1206FR-072K7L	2
R16, R18	68 ohms	Resistors_SMD:R_1206_HandSoldering	Panasonic	ERJ-8GEYJ680V	2
R4, R15	1k ohms	Resistors_SMD:R_1206_HandSoldering	Bourns	CR1206-JW-102GLF	2
R6, R7	10 ohms	Resistors_SMD:R_1206_HandSoldering	Bourns	CR1206-JW-100ELF	2
R8	47 ohms	Resistors_SMD:R_1206_HandSoldering	Yageo	RC1206FR-0747RL	1
SW1, SW3	SW_Push	Buttons_Switches_THT:SW_PUSH_6mm	Schurter	1301.9309	2
U1	SN65HVD12DR	Housings_SOIC:SOIC-8_3.9x4.9mm_Pitch1.27mm	Texas Instrument	SN65HVD12DR	1
U2	PIC32MX174F256B	Housings_SOIC:SOIC-28W_7.5x17.9mm_Pitch1.27mm	Microchip		1
	GSM2 CLICK	-	MikroElektronika	MIKROE-1375	1
	GSM ANTENNA	-	MikroElektronika	MIKROE-275	1